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Human factors analysis of Fiscal Year 90 to 97 rotary wing and TACAIR flight mishaps

Denham, Kenneth R.

Monterey, California. Naval Postgraduate School

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Monterey, California

THESIS

HUMAN FACTORS ANALYSIS OF FISCAL YEAR 90 TO 97 ROTARY WING AND TACAIR FLIGHT MISHAPS

by

Kenneth R. Denham

June 2000

Thesis Advisor:	John K. Schmidt
Second Reader:	Lyn R. Whitaker

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Human error is present in approximately 60 to 80 percent of all Naval Aviation (NA) flight mishaps (FMs). This indicates a need to identify the patterns and relationships of human error associated with NA FMs in order to develop tailored intervention strategies. This study uses the Human Factors Analysis and Classification System (HFACS), a human error oriented accident investigation and analysis process, to conduct post-hoc analysis of 77 rotary wing and 141 Tactical Aircraft (TACAIR) Class A and B human error FMs from Fiscal Year 90 to 97. This study indicates that Skill-Based Error, Decision Error, Adverse Mental State (AMS) and Crew Resource Management (CRM) are the predominant human error types associated with NA FMs. A nonparametric bootstrap simulation is performed for singular and combinations of human error types to develop the most effective intervention strategies. For the rotary wing community, the CRM human error type represents the best target for selected intervention strategies and potential cost savings. The AMS human error type provides the best target for selected intervention strategies and potential cost savings for the TACAIR community. The use of flight simulators is viewed as the most effective intervention strategy for both predominant human error types identified.

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HUMAN FACTORS ANALYSIS OF FISCAL YEAR 90 TO 97 ROTARY WING AND TACAIR FLIGHT MISHAPS

Kenneth R. Denham
Lieutenant, United States Navy
B.S., Florida State University, 1992

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requirements for the degree of

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Author: [redacted]

Approved by: [redacted]

John K. Schmidt, Thesis Advisor

[redacted]

Lyn R. Whitaker, Second Reader

[redacted]

Richard E. Rosenthal, Chairman
Department of Operations Research

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ABSTRACT

Human error is present in approximately 60 to 80 percent of all Naval Aviation (NA) flight mishaps (FMs). This indicates a need to identify the patterns and relationships of human error associated with NA FMs in order to develop tailored intervention strategies. This study uses the Human Factors Analysis and Classification System (HFACS), a human error oriented accident investigation and analysis process, to conduct post-hoc analysis of 77 rotary wing and 141 Tactical Aircraft (TACAIR) Class A and B human error FMs from Fiscal Year 90 to 97. This study indicates that Skill-Based Error, Decision Error, Adverse Mental State (AMS) and Crew Resource Management (CRM) are the predominant human error types associated with NA FMs. A nonparametric bootstrap simulation is performed for singular and combinations of human error types to develop the most effective intervention strategies. For the rotary wing community, the CRM human error type represents the best target for selected intervention strategies and potential cost savings. The AMS human error type provides the best target for selected intervention strategies and potential cost savings for the TACAIR community. The use of flight simulators is viewed as the most effective intervention strategy for both predominant human error types identified.

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LIST OF ACRONYMS

AAM	Attention to Action Model
ACT	Aircrew Coordination Training
AMB	Aircraft Mishap Board
AMS	Adverse Mental State
ANI	Assistant NATOPS Instructor
CFIT	Controlled Flight into Terrain
CI	Confidence Interval
CRM	Crew Resource Management
DE	Decision Error
DOD	Department of Defense
DON	Department of the Navy
FM	Flight Mishap
FRS	Fleet Replacement Squadron
FY xx	Fiscal Year xx
GEMS	Generic Error Modeling System
HFACS	Human Factor Analysis and Classification System
HFQMB	Human Factors Quality Management Board
MIR	Mishap Investigation Report
MONA	Monothetic Analysis
NA	Naval Aviation
NATOPS	Naval Aviation Training and Standard Operating Procedures
NI	NATOPS Instructor
NSC	Naval Safety Center
PAX River	Naval Air Station Patuxtent River, MD
SBE	Skill-Based Error
SETD	Systems Engineering Test Directorate
SIMS	Safety Information Management System
SRK Model	Skill, Rule and Knowledge Based Model
TACAIR	Tactical Aircraft

USA	United States Army
USAF	United States Air Force

EXECUTIVE SUMMARY

Human error has been implicated as the largest single factor in Naval Aviation (NA) Flight Mishaps (FMs). In addition, the average cost of all NA Class A and B FMs (all types and models of aircraft) for FY 98 is $17 million per FM, which results in a substantial total of approximately $775 million (Pruhs, 2000). In the midst of reduced budgets and limited resources, the NA FMs caused primarily by human error must be analyzed to determine the most effective intervention strategies for reducing human-error-related FMs. To address the need to identify the human error patterns in NA, post-hoc analysis of the 77 rotary wing and 141 Tactical Aircraft (TACAIR) Class A and B human error FMs from 1 October 1989 to 30 September 1998 is conducted using the Human Factors Analysis and Classification System (HFACS) taxonomy.

The HFACS is a taxonomy, which incorporates human error theory into accident investigation and analysis to answer the question "Why did the FM happen?" The HFACS taxonomy takes human error types and classifies them into 25 distinct human error groups. The HFACS taxonomy has a hierarchical relationship, which permits focused analysis on the 17 basic human error types related to NA. However, when analyzing the NA FMs that are principally due to human error, several human error types are normally cited as causal factors for each FM. These cited causal factors are not ranked in any order of importance. These facts make traditional statistical analysis techniques impractical, due to the non-mutually exclusive nature of the associated human error types in the HFACS taxonomy. The analysis for this study includes data exploration, cluster analysis, a nonparametric simulation model to predict future human error patterns, analysis of causal factors arrival rates and an assessment of the potential cost savings of intervention strategies.

The objectives of this study are to determine if predictive patterns and relationships of human error can be identified in NA FMs, if future NA FM rates and associated causal factors can be forecasted and if intervention strategies can be identified for the primary human factor patterns discovered. The analysis of this study using the HFACS taxonomy permits all three of the objectives to be met.

In this analysis, it is clearly evident that Adverse Mental State (AMS), Crew Resource Management (CRM), Skill-Based Error (SBE) and Decision Error (DE) are the

most prevalent forms of human error types present in the rotary wing and TACAIR FMs. When comparing the rotary wing and TACAIR results, the major difference is found in the pairwise dependency of causal factors. CRM is found to be significant in 12 of the 17 relationships and AMS is found to be significant in 9 of the 17 relationships between basic human error types for rotary wing. For TACAIR, AMS is found to be significant in 9 of the 17 relationships between basic human error types. When combining the rotary wing and TACAIR FMs, AMS is found to be significant in 11 of the 17 relationships between basic human error types.

Using the nonparametric simulation models developed for the rotary wing, TACAIR and combined rotary wing and TACAIR data sets, it is demonstrated statistically that future FM rates and their associated causal factors can be forecasted. The modeling of mishap events using a Poisson process is an effective technique, which allows the results of this analysis to focus potential intervention strategies. It is found that when looking at a 50 percent and 75 percent reduction in the mean causal factor arrival rates/100,000 flight hours, the largest potential cost savings are found in intervention strategies that target CRM for rotary wing FMs and AMS for TACAIR FMs.

To meet the goals set by the Human Factors Quality Management Board (HFQMB) in 1996 of reducing FMs caused by human error by 50 percent in three years and 75 percent in 10 years, it will require an aggressive and dedicated effort throughout NA to implement the necessary intervention strategies. Thus, targeting intervention strategies towards SBE, DE, AMS and CRM provide the best possible means to achieve the HFQMB goals. The most effective intervention strategies for the patterns of human error causal factors found in this study are associated with the use of flight simulators throughout NA. Simulators provide an opportunity to conduct training, to include the practice of emergency procedures, which would be dangerous or impossible to conduct in the actual aircraft. This study recommends six intervention strategies.

First, it is recommended that each pilot be scheduled for an "Emergency Procedure Simulator" every 90 days with a NATOPS Instructor or Assistant NATOPS Instructor. In addition, the Naval Safety Center (NSC) and the Systems Engineering Test Directorate (SETD) at Naval Air Station Patuxent River (PAX River) should design training scenarios for the simulator events that are based on actual FMs. It is

recommended that emergency procedures be initiated at different stages of a tactical simulator flight, instead of at the end of the event. It is recommended that aircrews be videotaped during simulator events. In addition, the pilots scan pattern should be tracked and recorded during the simulator flight. Finally, NSC and SETD PAX River should design an experiment to be conducted in the simulator in an effort to determine the common errors found for each NA community.

Due to the fact that simulators and aircraft are configured differently and that the missions and flight profiles are not the same for all aircraft communities, the implementation of these interventions will have to be tailored for individual communities and aircraft type. The intervention strategies are targeted at the fleet operational squadrons. However, where applicable, some of the strategies may carry over to the Fleet Replacement Squadrons (FRS) and flight school training.

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I. INTRODUCTION

A. OVERVIEW

Over the last 20 years, the aviation accident rate for both military and civilian aviation has decreased steadily (Shappell & Wiegmann, 1996). However, by 1992, accidents solely attributable to mechanical and environmental factors had been dramatically reduced, whereas those attributable to human error had been reduced by only 50%. Today, human error has been implicated in 60% to 80% of both military and civil aviation accidents (Nutwell & Sherman, 1997). In particular, over the last decade, it has been observed that the Naval Aviation (NA) Class A Flight Mishap (FM) rate of decline has slowed (Shappell & Wiegmann, 1997a).

In light of a series of human factor incidents in 1996, the Commander of the Naval Air Forces Pacific organized a Human Factors Quality Management Board (HFQMB) to reduce mishaps caused by human error (Nutwell & Sherman, 1997). The initial charter set the goals of reducing the NA Class A FM rate by 50 percent within three years and by 75 percent within 10 years (Naval Safety Center, 1996). One of the major impacts of the HFQMB has been the Naval Safety Center's (NSC) adoption of the Human Factors Analysis and Classification System (HFACS) taxonomy for classifying human error causes of FMs. However, no process has been developed to quantitatively evaluate the significance of patterns of human error causal factors in FMs. To decide what type and if intervention strategies are needed, it is important to understand the HFACS taxonomy and to quantitatively determine the existence of significant patterns of human error involved in FMs. In this thesis, the focus is on using quantitative methods to determine which patterns of human error are most prevalent for NA rotary wing and TACAIR FMs.

B. BACKGROUND

The Department of the Navy (DON) (1993) defines a NA mishap as an unplanned event or series of events directly involving naval aircraft, which result in $10,000 or greater cumulative damage to naval aircraft or personnel injury. A FM is a mishap in which there was $10,000 or greater Department of Defense (DOD) aircraft damage or loss of an aircraft, and intent for flight for the aircraft existed at the time of the mishap. Other property damage, injury, or death may or may not have occurred. A Class "A" FM

exists when the total cost of property damage (including all aircraft damage) is $1,000,000 or greater; or a naval aircraft is destroyed or missing; or any fatality or permanent total disability occurs with direct involvement with the aircraft. While a Class "B" FM exists when the total cost of property damage (including all aircraft damage) is $200,000 or more, but less than $1,000,000 and/or a permanent partial disability, and/or the hospitalization of five or more personnel.

When a NA FM occurs, an investigation is conducted to determine the causal factors associated with the mishap. Most mishaps result from two or more causal factors. The investigation makes no attempts to rank the causal factors as "direct," "primary," "principal," etc… because without any of them there would be no mishap (DON, 1993). Attempting to name a single factor as most important would be like trying to pick out the most important leg on a chair (Woodcock, 1989). For classifying human error, the NSCs HFACS taxonomy is being integrated into the OPNAV INSTRUCTION 3750.6Q (DON, in press).

The fact that there are usually several causal factors for each FM makes analysis of causal factors of FMs quite difficult. With the exception of Jensen (1999), there are no studies which apply quantitative methods to identify human error patterns in FMs. Jensen (1999) uses the HFACS taxonomy to identify human error patterns in Naval Tactical Aircraft (TACAIR) FMs from fiscal (FY) 90 to FY 97. The results of his study reveal that of the 17 human error types in the HFACS taxonomy, "Adverse Mental State" is the most prevalent. In fact, it occurred in 68% of the TACAIR FMs, which were analyzed. In addition, Jensen (1999) uses a nonparametric bootstrap (Elfron & Tibshirani, 1993) to assess the impact of intervention strategies.

C. OBJECTIVE STATEMENT

This study will use HFACS taxonomy to classify human errors in United States Navy and Marine Corps rotary wing and TACAIR Class A and Class B FMs during the period FY 90 to FY 97. The first objective is to statistically determine which patterns of human error are most prevalent and significant. A second objective will be to evaluate the effectiveness of the proposed intervention strategies.

D. PROBLEM STATEMENT

As the military is faced with continued operating and procurement budget reductions, the present mishap rate of approximately 2 Class "A" FM's per 100,000 flight hours (20+ aircraft per year) becomes significant (Schmidt, 2000). Human error as the most significant contributing factor in FMs must be addressed and support for intervention strategies must be gained. Jensen (1999) examined NA tactical aircraft (TACAIR) FMs for patterns of human error and identified a potential intervention strategy. However, his results cannot be transposed to the Naval rotary wing communities. Therefore, analysis needs to be conducted for these communities as well. This will permit the comparisons of human error patterns between rotary wing and TACAIR communities, which will result in the implementation of the most effective intervention strategies for NA.

This thesis will conduct a human factor analysis to identify patterns in human error types that contribute to FMs in Navy and Marine Corps rotary wing and tactical aircraft, to identify potential interventions, and to investigate their possible impact. This study will investigate the following questions:

1. Can predictive patterns and relationships of human error be identified in Naval rotary wing and TACAIR FMs?

2. Can future Naval rotary wing and TACAIR FM rates and their associated causal factors be forecasted?

3. Can potential intervention strategies be identified for the primary human factor patterns found?

E. SCOPE AND LIMITATIONS

This study will examine FMs of NA rotary wing and TACAIR Class A and Class B FMs which occurred from FY 90 to FY 97. The focus of this study will be all rotary wing and TACAIR Class A and Class B FMs attributable to human error. The following naval aircraft are considered rotary wing for this study: AH-1G, AH-1J, AH-1T, AH-1W, HH-1K, HH-1N, UH-1E, UH-1H, UH-1N, HH-2D, SH-2F, SH-2G, CH-3E, HH-3A, HH-3D, SH-3A, SH-3D, SH-3G, SH-3H, SH-3J, UH-3A, UH-3H, VH-3A. VH-3D, OH-6B, CH-46A, CH-46D, CH-46E, HH-46A, HH-46D, UH-46A, UH-46D, CH-53A, CH-53D, CH-53E, MH-53E, MH-53J, RH-53D, UH-57A, OH-58A, HH-60H, HH-60J, SH-60B,

SH-60F, UH-60A, UH-60N, VH-60A, VH-60N, and HH-65A. The following naval aircraft are considered tactical aircraft for this study: A-4E, A-4F, A-4M, A-4Q, A-6A, A-6B, A-6E, A-7B, A-7C, A-7E, A-7F, AV-8B, AV-8D, EA-6A, EA-6B, EA-7L, F-4A, F-4G, F-4J, F-4N, F-4S, F-5E, F-5F, F-9F, F-14A, F-14B, F-14C, F-14D, F-16N, F-18A, F-18B, F-18C, F-18D, F-18E, F-18F, KA-6B, KA-6D, OA-4M, RF-18A, and RF-4B.

The next chapter contains an introduction to human error, human factors theory, the HFACS taxonomy and applications of the HFACS taxonomy. Chapter III discusses the methodology used in this study. The results of the exploratory data analysis, analysis of accident arrival rates, simulation models, analysis of causal factor rates and potential intervention cost savings are provided in Chapter IV. Finally, a research summary, conclusions, and recommendations are contained in Chapter V.

II. LITERATURE REVIEW

A. OVERVIEW

In the past, the focus of most aviation accident investigating and reporting systems is to concentrate on identifying the engineering and mechanical failures associated with aviation mishaps (Wiegmann & Shappell, 1997). Also, the investigations are normally conducted, as well as the reports are normally prepared by engineers and former operators, instead of an investigator with aviation psychology or human factors background. These systems are under the mythical mindset that once an accident could be attributed to "pilot error" then the problem is solved and the case could be filed (Hawkins, 1993). The pilot error concept focused rather more on what happened than why it happened (Shappell & Wiegmann, 1997a; Hawkins, 1993).

A lack of a human factors based reporting system meant that analyses had to be conducted on databases that were not conducive to identifying human error patterns and developing intervention strategies for them. For this reason, the U.S. Navy had to develop a new taxonomy designed to classify human error in Naval Aviation (NA) mishaps (Shappell & Wiegmann, 1997a). Wiegmann and Shappell (1997) in developing a new human factor oriented taxonomy, had to decide whether to use an existing reporting system or to move to a totally new one based on human factors. They determined it was not feasible to totally abandon the current system and incorporate a new human factor based system. First, all the data that was in the existing database would be lost and would require years to acquire sufficient data to identify potential trends. In addition, mishap investigators would have to be trained to use the entirely new reporting system.

Holladay, an accident investigation instructor at the University of Southern California, believed that the first element of the accident prevention fundamentals is the matter of "known precedent" (Miller, 1988). Known precedent simply means that it is rare, if ever, that new accident causal factors appear. Since the existing database already answered the "what happened" question, the new taxonomy would have to permit the answering of the "why did it happen" question. The Navy decided to base their studies and taxonomy on a "Taxonomy of Unsafe Operations" which is specifically designed for the purpose of classifying human error in NA flight mishaps (FM). This classification system has evolved and is now called "HFACS—Human Factors Analysis and

Classification System" (Jensen, 1999). Several theories and studies exist which attempt to explain human factor issues as they pertain to human error (Reason, 1990; Senders & Moray, 1991). However, this discussion will focus on the theories and models used by Shappell and Wiegmann (1997a) to develop the HFACS taxonomy.

B. HUMAN ERROR

In 1980, the Clambake Conference on the Nature and Source of Human Error met in Columbia Falls, ME to examine the fundamentals of human error (Senders & Moray, 1991). The 18 scientists, who attended the conference, submitted a position paper based on queries of human error causes, prediction, and reduction prior to attending the conference. When compiling the results of the queries, a wide range of responses was observed. In fact, it was determined that some authors do not even accept a definition for human error (Jensen, 1999). While, others, such as Reason and Norman, use a reference to "slips" or "mistakes," as well as notions of "intentions," when explaining the term (Senders & Moray, 1991). However, an attempt to determine a unified summary of views held by the participants prior to the meeting produced the following generally accepted definition of human error (Senders & Moray, 1991):

> Something has been done that was not intended by the actor; not desired by a set of rules or an external observer; or that led the task or system outside its acceptable limits.

Depending on the author's point of view, errors will imply a deviation from intention, expectation or desirability.

Reason (1990a) uses the following working definition of error:

> Error will be taken as a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency.

This definition will be necessary in an effort to classify human error forms by differentiating between intentions and error. A series of planned actions may fail to achieve their desired objective because the plan did not go as planned or because the plan itself was inadequate (Reason, 1990a).

When addressing human error, Reason and Norman use *psychological mechanisms*, such as slips and mistakes, to address the form of error committed (Senders & Moray, 1991). Reason (1990a) defines slips and lapses in the following manner:

> Slips and lapses are errors which result from some failure in the execution and/or storage stage of an action sequence, regardless of whether or not the plan which guide them was adequate to achieve its objective.

Slips can be thought of as performance of an action that is not intended (Norman, 1981). Lapses are more covert in nature and take the form of memory failures. These memory failures are manifested in the form of omitted items in a checklist, place losing, or forgot intentions (Shappell & Wiegmann, 1997b).

Reason (1990a) states:

> Mistakes may be defined as deficiencies or failures in the judgmental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision-scheme run according to plan.

Mistakes are harder to detect than a slip or lapse, because humans are consciously trying to detect a departure of action from intention (Reason, 1990a). Mistakes can go unnoticed for years. Unfortunately, mistakes are typically discovered as the result of an accident.

Rasmussen uses a taxonomy based on human behavior by determining what level of the cognitive process did the error take place (Senders & Moray, 1991). Humans will use different cognitive control mechanisms depending on the familiarity with the work situation/environment (Rasmussen, 1987a). These cognitive levels are based on a person's past experiences, rules or conceptual models and knowledge of the system involved. Humans are goal-oriented by nature and exhibit a teleological behavior, which means a person's performance is modified by signals received from the goal (Rasmussen, 1983). Rasmussen (1987a) contends that human error arises from man-task mismatches in the performance of task by a person to reach his goals.

Primarily, the focus has been on operator error, which refers to the worker whom is directly working with the system. Reason (1995) addresses this type of error as active failures within the organization. Since accidents cannot be directly controlled by an organization, the organization can only defend against hazards (Reason, 1990b). Similarly, an organization cannot eliminate human propensities for committing errors and

violations. Instead, the organization can only attempt to manage the internal factors that foster unsafe acts by human operators (Reason, 1990b). Therefore, the issue of organizational error needs to be addressed.

Reason (1990b) refers to latent failures, which Reason (1997) now calls latent conditions, as being analogous to resident pathogens in the human body, because they will cause the breakdown of a system's defenses within the organization. Latent conditions occur in the upper echelon of an organization and are created by people who are removed from the hazard (Reason, 1995). These latent conditions are manifested by management allocating finite resources (i.e., planning, forecasting, scheduling, regulating, designing, maintaining, etc.) between production and safety (Reason, 1990b). Once latent conditions are formed, they are transmitted through the active failure pathway to the workplace where they produce an atmosphere (e.g., high workload, deficient equipment, time pressure, fatigue, low morale, etc.) that promotes unsafe acts (Reason, 1995). In addition, the latent conditions are transmitted through the latent failure pathway directly to the organization's defenses and will weaken the organizations safety climate through system design, lack of training, inferior hardware, missed maintenance, substandard procedures, goal conflicts and the like (Reason, 1990b). Therefore, human error could more appropriately be defined as mistakes made by humans operating the system, humans who designed the system, humans who supervise the operator, humans who trained or advised the operator and humans who manage the organization (Wickens, Gordon & Liu, 1998).

C. HUMAN FACTORS THEORY

1. The Domino Theory

Heinrich introduced the first theoretical framework for accident causation in 1931. His theory and concepts were formulated into what is known as the "axioms of industrial safety" (Petersen, 1984). Prior to his theory, safety practitioners concentrated on the physical conditions of the plant, which included cleanliness and material readiness rather than the human component in the process. The first axiom deals with the theory of accident causation now known as the "domino theory." The first axiom is defined as:

> The occurrence of an injury invariably results from a completed sequence of factors—the last one of these being the accident itself. The accident in turn is invariably caused or permitted directly by the unsafe act of a person

and/or a mechanical or physical hazard (Heinrich, Petersen & Roos, 1980).

This axiom leads to the fact that an injury is the result of an accident, and the accident is the result of the factor (unsafe act or mechanical/physical hazard) that immediately precedes it. He states that the sequence is similar to a row of dominos and that the sequence can be broken if one of the preceding dominos is eliminated (Heinrich, Petersen, & Roos, 1980). As a result, accident prevention is focused in the middle of the sequence, which is the unsafe act or mechanical/physical hazard.

Heinrich's theory was revolutionary at its introduction; however, over the years it was found to put too much emphasis on the human operator. Therefore, Bird (1974) revised Heinrich's "domino theory." The following is the list of Bird's revised five-step sequence of the "domino theory:"

1. Safety and Management: These contain supervisory issues.
2. Basic Causes: These include human factors, environmental factors, or job related factors.
3. Immediate Causes: These include unsafe acts by the operator and/or mechanical failures of the system.
4. Accident: This is the result of the break down in the system's interactions.
5. Injury and Property Damage: These are the result of the system interfaces being severed.

His revision introduced the concept of management error into the accident causation sequence.

2. The SHEL Model

Edward (1988) developed the "SHEL Model" to provide a conceptual model of the Human and Machine system interfaces. The components of the "SHEL Model" are Software, Hardware, Environment, and Liveware, which all interact with one another. The components of the SHEL model are defined as follows (Edwards, 1988):

1. Software: consists of the non-physical elements of the system and any related documents. These elements include more than just computer programs, but also encompass the rules, regulations, standard operating procedures, checklists, and practices that govern how a system operates.

2. Hardware: consists of the buildings, vehicles, equipment, and materials that comprise the system.

3. Environment: consists of more than just the surrounding atmosphere, but also includes the effects the system has on the environment. In addition, the economic, political, and social factors are included.

4. Liveware: consists of the humans involved with the system. The person can be internal or external to the system.

The interactions and relationships between the components are represented by interfaces, which symbolize the flow of information or energy between the components.

Nearly all technological systems are not only operated by humans, but they are also designed, constructed, organized, managed, maintained and regulated by them as well (Reason, 1995). For this reason, Liveware is considered the hub of the model and all other components must be designed to facilitate and account for human limitations in the interactions of the interfaces (Hawkins, 1993). The main assumption of the SHEL Model is that the system will fail when an interface is severed or a mismatch exists between any two of the four components, or when one of the four components fails (Schmorrow, 1998). This study focuses on the mismatches between the Liveware component (hub) and the other components of the model.

The first example of a Liveware mismatch with the other components is a Liveware and Hardware mismatch, which is manifested through system design. This mismatch is usually the result of knobs, levers, switches or controls that are poorly located or lack proper coding and cause the operator to commit errors when operating the system (Hawkins, 1993). Secondly, a Liveware and Software mismatch can be manifested when a checklist or manual is improperly indexed. As a result, the information access cost for the pilot will be too large and the pilot will be unable to obtain the needed information or emergency procedure in a timely manner. The Environment component encompasses more than just the surrounding atmosphere, but also includes the effects the system has on the environment, which can cause a Liveware and Environment mismatch. For example, aircraft generate tremendous amounts of noise and pilots are subjected to this stress for extended period of times, which may affect the decision making of the pilot. The final component mismatch is a Liveware and Liveware

mismatch. A typical scenario that would cause this mismatch is one where a senior pilot who is very authoritative and overbearing is paired with a pilot who is unassertive and very junior in rank.

3. The Attention Resource Model

Although information processing models are not necessarily a failure model, most human error models use information processing theory, because it is one of the major limitations for human beings (Wiegmann & Shappell, 1997). Wickens et. al. (1998) defines an information model framework that consists of four stages, which are sensory stage, perceptual stage, cognitive stage and action stage. Wickens and Flach (1988) describes the four stage model as the process of information progressing through the various stages and the mental operations that act as a go-between the stimulus input and the response execution. The process begins with stimuli entering the senses and being temporarily stored in working memory. The stored stimulus goes through a process of pattern recognition and is transformed into meaningful information. At this point, the information must be acted upon, stored for future use, or re-evaluated for new alternatives. The model also incorporates a feedback loop, which allows for response verification by providing the output of a response as a stimulus to the senses (Norman, 1981).

Due to the limitations of the various stages and components of the "information processing model," an additional component, known as the attention resources or attentional mode, is needed (Wickens, 1984). There is typically more than one cue or cognitive processes present and it is simply not possible to detect or act upon all cues or stimuli received simultaneously. Therefore, the attentional mode must prioritize which cognitive task to perform. This attentional mode can be thought of as a chalkboard, with limited space, where the working memory performs its cognitive processes (Jensen, 1999). It is important to note that this attentional mode is voluntary and at the control of the human operator. A pilot who misses a radio call while he is concentrating on an emergency situation, demonstrates this fact.

In the action stage, a person will typically use cognitive heuristics, vice a normative model to make decisions (Wickens, Gordon & Liu, 1998). Heuristic cognition involves the user seeking for cues and assessing the current situation of the system based

on knowledge of the system and past experiences (Rasmussen, 1987a). For example, the pilot will scan and monitor the engine instruments while in flight and the first indication that an abnormal situation exists is usually a caution light or an indicator being in an abnormal range. Based on the cues present, the pilot must generate and evaluate a number of hypotheses from long-term memory using both semantic and episodic memory. This evaluation is conducted by the pilot gathering additional cues from his instruments in order to confirm or disprove each hypothesis, time permitting of course (Wickens & Flach, 1988). Once the pilot evaluates all or as many as possible of the hypotheses, he must now make a decision as to which action to take.

The use of heuristics is subject to several limitations or biases, which are related to the cues that are used to generate the hypotheses (Wickens & Flach, 1988). Only a limited number of cues can be brought into memory, as well as only a limited number of hypotheses. Also, unintentional weights will typically be given to the first few cues and the hypotheses generated based on these cues will lead to the ignoring of later cues that in reality may present a better representation of the system's status (Wickens & Flach, 1988). Typically, the first hypothesis brought into working memory is usually the easiest or most recently considered hypothesis, which can make the problem seem common place and can lead to the user being over confident in the hypothesis generated (Wickens, Gordon & Liu, 1998). Once a hypothesis is selected, additional cues are usually ignored. When the user does seek additional cues, usually only information that supports the selected hypothesis is sought, which results in confirmational bias (Senders & Moray, 1991).

4. The Attention to Action Model

Norman and Shallice's Attention to Action Model (AAM) is directly linked to the attentional and schema control modes of the information processing model (Jensen, 1999). The AAM provides for two types of control structures, horizontal threads and vertical threads (Reason, 1990a). The horizontal threads consist of strands of specialized processing structures, referred to as schemas. Norman (1981) defines a schema as an organized body of knowledge, including procedural knowledge that can direct the flow of motor activity. An individual schema is limited in the amount of actions or knowledge it can contain. Therefore, any given action requires the activation of an ensemble of

schemas, which are organized in a heterarchical control structure (Norman, 1981). This structure facilitates the process of only having to initiate the necessary schemas to complete the task at the highest level of memory representation. Note that it is possible to have numerous schemas activated at the same time.

Horizontal threads are for habitual activities without the need for moment-to-moment attentional control. They receive their triggering conditions from the environment or from previously activated schemas (Reason, 1990a). When current active schemas are insufficient to achieve a goal, the vertical threads provide a higher-level attentional process. This process is necessary for unique or critical situations and it interacts with the horizontal threads to increase or to decrease the schema activation levels to modify a particular action (Reason, 1990a). Also included are motivational variables, which also influence schema activation along the vertical threads, but are assumed to work over much longer time periods than the attentional resources (Jensen, 1999).

Norman (1981) classifies three major sources of action slips, (a) the formation of the intention, (b) activation, and (c) triggering. The slips associated with the formation of the intention are manifested by a misclassification of the situation or by an ambiguous or incompletely specified intention. An activation slip is characterized by a schema is unintentionally activated or a schema loses its activation before its appropriate time. Finally, the triggering slip is when the schema is properly selected, but it is triggered improperly (e.g., wrong time or not at all).

5. The Skill, Rule and Knowledge Model

Like Norman and Shallice, Rasmussen's model is similar to the traditional information processing model, in that it begins with the introduction of cues and their perceptions, which are processed through stages to produce an output (Wiegmann & Shappell, 1997). The Skill, Rule and Knowledge (SRK) model uses naturalistic decision making, which is when people use their experiences to make decisions in field settings (Wickens, Gordon & Liu, 1998). The SRK model framework divides the cognitive control of a person into three different levels, which are skill-based level, rule-based level and knowledge-based level (Rasmussen, 1983).

At the skill-based level, a person will be extremely familiar with the task at hand and performance will be driven by automatic responses based on stored patterns, or schemas (Rasmussen, 1987a). Errors at this level are associated with misdirected attention—person misses a cue which would cause the automatic response or begins to think about the response and interrupts the automatic response (Wickens, Gordon & Liu, 1998). At the rule-based level, a person will be familiar with the system but lack the extensive experience required to operate with automatic response. A person's actions are governed by stored rules or procedures of the type "if (state) then (diagnosis)" for trouble-shooting task or "if (state) then (remedial action)" for operational task (Reason, 1990a). Errors manifest at the rule-based level due to a misclassification of the situation and as a result, the wrong rule is applied or a person can forget the procedures or recall incorrect procedures for a specific rule (Reason, 1990a).

The knowledge-based level is where novel or new situations are encountered and a person's actions will have to be planned using conscious analytical and cognitive processes and stored knowledge (Wickens, Gordon & Liu, 1998). At this level, it is necessary for attentional resources to play a large role in coordinating these processes. The errors associated with this level involve the limitations discussed in the information processing model and the fact that the person will have incomplete or incorrect knowledge for the situation (Rasmussen, 1987a).

Rasmussen's SRK model differs from other decision theorists who represent their stages in a linear fashion. The SRK model is analogous to a stepladder, with the activation and execution stages on the bottom and the knowledge base interpretation and evaluation stages at the top (Reason, 1990a). Intermediates on either side are the rule-based stages. The SRK model is formatted to represent the shortcuts that people use to make decisions in real-life situations. These shortcuts are usually in the form of highly efficient but situation specific stereotypical reaction, where the observation of the system state leads automatically to the selection of remedial procedures without the slow and effortful knowledge based processing (Reason, 1990a). This framework permits the leaping between any of the decision stages. This strategy is subject to human error, because it relies heavily on the appropriateness of a person's past experiences (Jensen, 1999). Typically, a person's cognitive control will cycle back and forth through all three

levels. However, it is possible for more than one or even all three levels to be operating simultaneously (Reason, 1990a).

6. The Generic Error Modeling System

Reason's (1990a) "Unsafe Act Model" is framed around the Generic Error Modeling System (GEMS) and is directly incorporated into the HFACS taxonomy (DON, in press). Reason's (1987) GEMS model is another rule-based model that uses the attentional and schematic control modes. In fact, GEMS uses Rasmussen's skill, rule, and knowledge-based model as its foundation. In the GEMS model, Reason (1990a) contends that there are three basic error types. The first type of error is skill-based slips or lapses, which occur prior to problem detection. The next error type is mistakes, which is separated into rule-based mistakes and knowledge-based mistakes that appear in subsequent phases of problem solving. The key to determining which level of performance that the error occurred is to determine the answer to the question of whether the individual was engaged in problem solving at the time the error occurred (Reason, 1987).

Control of human action is determined from the interactions between two control modes: the attentional and schematic modes (Reason, 1987). Performance at the skill-based level is the result of automatic sensorimotor responses, which after an intention is formed occur automatically without conscious control (schematic mode). An individual will need to check up on these automated responses to ensure the actions are according to plan and to ensure the plan is still adequate for the situation. Slips and lapses are manifested by attentional mode or monitoring failures, which are inattention or over-attention (Reason, 1990a).

Inattention is the fact that the individual failed to monitor the sequence of automatic responses at some critical point and as a result the responses will be driven towards the most frequent response, even though the individual's intention was otherwise (Reason, 1990a). For example, after landing, a pilot intends to taxi through the wash rack prior to taxing to his parking spot on the flight line. This is a deviation from the well-learned schema of simply taxiing to his parking spot. Therefore, a new schema will have to be formed and will have to be activated once at the proper location on the taxiway. During the process, the pilot gets distracted with radio communication and post-landing

checklist, causing him to miss his turn-off for the wash rack. The pilot continues on with the well-known schema of taxing to his parking spot, but now with a dirty aircraft (Norman, 1981). Over-attention is when a conscious inquiry of the progress of an ongoing sequence results in an assessment of being at a different point in the sequence than actually has been achieved. This will possibly result in mistiming of subsequent procedures.

Rule-based and knowledge-based levels of performance become relevant after the individual becomes consciously aware of the problem and therefore can be thought of as the problem solvers (Reason, 1987). The GEMS model parallels Norman and Shallice's model using their concept of schemas. The GEMS model asserts that when an individual is presented with a problem, he will search for a familiar schema or rule based logic from previous experience (Jensen, 1999). This occurs at the rule-based level before attempting to solve the problem at the more difficult knowledge-based level, which possibly should have been the starting point in the first place (Reason, 1990a).

The errors at the rule-based level manifest themselves in the form of misapplication of good rules and application of bad rules (Reason, 1990a). Typically, the misapplication of good rules is the result of the conditions of the system not perfectly matching the parameters associated with the rule. The application of bad rules is the result of improperly or inadequately programmed rules or rules that will lead to an inadvisable response. Errors associated with the knowledge-based level are associated with the fact that the knowledge relevant to the problem space is nearly always incomplete and often inaccurate (Reason, 1990a). At this level, the individual is subject to the limitations and biases as discussed in the information processing model.

D. HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM

Errors do not appear in random, unpatterned fashion independently of their surrounding circumstances (Nagel, 1988). Their frequency of appearance will depend upon a wide range of variables, some which are properties of the individual—such as age or state of fatigue—and others which are related to the interfaces between the individual and the components with which the individual interacts. Therefore, if a safety program is established and incorporates an effective reporting system with an appropriate database,

the pattern and trends of errors, particularly human error, can be identified and effective intervention strategies can be applied.

As stated earlier, the existing non-human factor based database already answers the what happened questions about an accident. In order to tell the why an accident happened, the database must be structured to detect patterns and trends. "In any area of scientific study, it is necessary to develop a clear-cut system of classification" (Senders & Moray, 1991). This classification system is known as taxonomy. If an understanding of the nature, origins, and causes of human error is desired, then it is necessary to have an unambiguous classification scheme that has a theoretical basis of human error (Senders & Moray, 1991). A universally accepted, or off-the-shelf, taxonomy of human error does not exist. In fact, there are almost as many taxonomic schemes as there are people interested in the study of error (Wiegmann & Shappell, 1997).

When Wiegmann and Shappell (1997) were developing the HFACS taxonomy, the existing naval aviation accident database, with known deficiencies, is used to test the utility of traditional human-error frameworks. The frameworks chosen are (a) four-stage model of information processing, (b) internal human malfunction derived from Rasmussen's SRK model, (c) and Reason's Unsafe Acts Model. One of the results of their study is that all three frameworks are able to classify at least 86.9% of the 289 pilot-causal factors. Additionally, the frameworks accounts for at least 80.4% of the 4,279 accidents in the database. However, it is apparent that the information processing model accounts for the fewest pilot causal factors and the lowest number of accidents. This is to be expected since the SRK model and unsafe acts model are both failure models that build upon the traditional information processing model (Wiegmann & Shappell, 1997).

No matter what framework is used, it must be tailored to fit the task at hand and the human-machine interface (Rasmussen, 1987b). When Wiegmann and Shappell (1997) tests the utility of the existing database, it is found that the three traditional frameworks of human error left some pilot-cause factors unexplainable. The reason is that those frameworks are not designed specifically for aviation and do not account for some forms of errors that may occur. A further illustration of the need to tailor the taxonomy based on the task and operations involved can be seen in the results of Lacy's (1998) study. The HFACS taxonomy was developed by Shappell and Wiegmann (1997a) to be used by the

NSC to analyze NA mishaps resulting from human error. Lacy (1998) discovers that the HFACS taxonomy is able to classify 459 of 496 or 92.5% of the causal factors in the mishap reports of Naval Afloat Class A mishaps over the period of fiscal year 1987 through fiscal year 1996. This demonstrates the fact that even within the same organization, the taxonomy and database structure of a safety reporting system must be tailored to fit the form of errors that will occur in the organization's various operations.

The HFACS taxonomy incorporates the human error theory and human-failure models already discussed. As in the "Domino Theory", HFACS contends that accidents are not caused by a single event, but are often the result of a sequence of events (Department of the Navy, in press). Reason (1995) asserts that there are two types of failures. The first is active failures, which can be categorized as the result of the actions or inaction's of the operator that are believed to have caused the accident. Active failures are felt almost immediately by the system. The second type of failure is latent failures, or conditions, which can be characterized by errors committed by individuals within the supervisory chain of command or elsewhere in the organization that effect the sequence of events which lead up to the accident. Latent errors' consequences can lie dormant within a system for years, until they combine with other factors, which breach an organization's defenses (Reason, 1990a). The "SHEL Model" provides a conceptual model to represent which interactions of the system broke down to allow the error to occur. To determine the human error involved, HFACS draws from both Rasmussen's skill-based, rule-based and knowledge-based levels of performance; attentional and schematic control modes; and Reason's "Unsafe Acts Model."

HFACS describes four levels of failure: 1) Unsafe Acts—active failure, 2) Preconditions for Unsafe Acts—active and latent failures, 3) Unsafe Supervision—latent failure, and 4) Organizational Influences—latent failure (Department of the Navy, in press). Also, HFACS incorporates a maintenance extension to examine the human factors of maintenance personnel in the same way as with the aircrew. If interested in a study involving maintenance human error, see Schmorrow (1998). An excerpt from OPNAV 3750.6R (Appendix O) HFACS Taxonomy is located in Appendix F.

E. APPLICATIONS OF THE HFACS TAXONOMY

Human factors analysis is one of the Naval Safety Centers (NSC) most prominent initiatives (NSC, 1999). The HFACS taxonomy separates the 289 types of separate human error and categorizes them into 25 basic human factor categories, which allows for focused research (Jensen, 1999). Since the development of HFACS taxonomy, several agencies, including NASA, the National Transportation Safety Board, the Federal Aviation Administration, the Gore Commission on Aviation Safety, the civilian airlines, and academia have expressed interest in the possibility of using the HFACS taxonomy in the investigation of commercial and general aviation mishaps (NSC, 1999). However at this time, the amount of available analysis using the HFACS taxonomy is limited. This section covers some of the analysis which has been conducted using the HFACS taxonomy.

1. Controlled Flight into Terrain

Shappell and Wiegmann (1997b) uses the HFACS taxonomy to conduct analysis on controlled flight into terrain (CFIT) accidents. They use two data sets for their analysis. The first data set includes NA Class A accidents classified as CFIT by the NSC between November 1983 and August 1995. For comparison purposes, the second data set consists of Class A tactical aircraft (TACAIR) and Class A rotary wing accidents occurring between November 1989 and September 1995. The second data set does not include those accidents that are previously classified as CFIT. Ninety-one of 144 NA Class A mishaps that are classified as CFIT has determined causal factors, which yields 493 human causal factors. After removing those mishaps classified as CFIT, a comparison sample of 108 Class A TACAIR and rotary wing mishaps yields 559 human causal factors.

The results of Shappell and Wiegmann's (1997b) analysis reveals that, in general, CFIT mishaps are primarily associated with adverse mental states (mental fatigue and loss of situational awareness) and adverse physiological states (spatial disorientation). However it was surprisingly to discover the frequency of CFIT mishaps associated with aircrew mistakes and violations, particularly CFIT accidents that occurred during daylight. In addition, nearly half of all CFIT mishaps occur during broad daylight. When examining the differences between the two data sets (using chi-square analysis), it is

determined that a larger proportion of CFIT mishaps are associated with supervisory violations, aircrew readiness violations,. adverse mental states and physiological states than TACAIR and rotary wing mishaps.

2. Inter-service Comparisons

The NSC (1998) uses the HFACS taxonomy to conduct comparisons of Class A mishaps that involved human causal factors between NA and the Air Force (USAF) for TACAIR and between NA and the Army (USA) for rotary wing. Although the number of years examined is approximately the same, the data are not collected from precisely the same periods. The USAF has 72 Class A TACAIR FMs attributed to human cause factors from 1991 to 1997; the USA has 62 Class A rotary wing FMs attributed to human cause factors from 1992 to 1997; and NA has 120 Class A TACAIR FMs and 48 Class A rotary wing FMs attributed to human cause factors from 1990 to 1996.

Naval Aviation consistently shows higher numbers in most cause factor categories than its counterparts (NSC, 1998). The most pronounced difference is in the number of mishaps that have violations as a causal factor. In the TACAIR community, NA shows 38% of its mishaps are attributable to violations, vice 7% in the USAF TACAIR mishaps. Similarly, 50% of mishaps for NA rotary wing include violation cause factors, vice 28% for the USA rotary wing mishaps. In addition, crew resource management (CRM) shows marked differences. For TACAIR, 51% of NA mishaps include CRM cause factors, vice 17% for the USAF. Likewise, for the rotary wing communities, 75% of NA mishaps involve CRM cause factors vice 39% for the USA. The other causal factors show less marked differences in occurrences.

This study makes NA look like the "bad boys" of military aviation (NSC, 1998). However, there are possible reasons that may contribute to the differences. First, each service's aviation mishap boards report their investigations differently. Another factor is the difference in the organizational culture of the services. The Navy/Marine Corps rule of thumb has traditionally been: "you can do it unless there is a rule that says you can't," while their sister services rule of thumb seems to be: "you can't do it unless there is a rule that says you can" (NSC, 1998). Lastly, the time periods are not precisely the same and can introduce confounding influences that are not explained.

3. Naval Aviation Tactical Aircraft

Jensen (1999) uses the HFACS taxonomy to identify human error patterns and important relationships between the causal factors in Naval TACAIR FMs from fiscal year (FY) 90 to FY 97. There are 122 Class A TACAIR FMs and 19 Class B TACAIR FMs, from FY 90 to FY 97 that are categorized as human factors FMs. In his study, Jensen (1999) examines the correlation between causal factors, performs cluster analysis to identify groupings of human error types, and uses the Poisson Process to produce a nonparametric bootstrap simulation model.

The results of his study reveal that of the 17 basic human error types in the HFACS taxonomy, adverse mental state is the most prevalent. In fact, it occurs in 68% of the TACAIR FMs, which are analyzed. In addition, adverse mental state has an important subset relationship with 12 out of the 17 basic human error types. Therefore, if intervention strategies are formed to address adverse mental state, these strategies would affect many other possible causal factors in a potential FM.

F. SUMMARY

Whenever a naval aircraft mishap occurs, it is a signal that the Naval Aviation Safety Program has failed because the purpose of the program is to preserve human and material resources (Department of the Navy, 1993). This preservation of resources can only be accomplished through identifying the causes of the mishap and then through analysis determining the why. Therefore, it is not enough to say 60% to 80% of all aviation mishaps involve some form of human error. No effective intervention strategies can be implemented using strict percentages. Instead a taxonomy that is based on human error theory and a database that is structured to classify human error is needed at the foundation of any safety program for an organization that involves human operators.

Wiegmann and Shappell (1997) asked, whether to revamp or develop anew? It is determined that post accident data located in the database can be organized using traditional models of information processing and human error, but some factors are unable to be classified. Therefore, the Navy has to develop a new theoretical human failure framework model for classifying human error. Also, the database has to be restructured to create a relational database. However, these two decisions allow the existing reporting system to remain constant and prevent from having to train all the

investigators on an entirely new system. In addition, due to only restructuring of the database, all the past mishap data is preserved.

HFACS is a comprehensive model of human error and a natural relational database for which to study human error. HFACS permits analyst to use statistical tools to study the human error and to evaluate the presence of human error patterns or relationships. Shappell and Wiegmann (1996) stress the need to conduct analysis of human error for specific communities (i.e., TACAIR, rotary wing, etc.) when considering various factors, such as time-of-day for mission or phase of flight (i.e., take-off, in-air, or landing). Jensen's (1999) study, which examines at all Class A and Class B TACAIR FMs with human cause factors from FY 90 to FY 97, is the first step in this direction. In his study, Jensen (1999) is able to identify adverse mental state as the human causal factor that is most prevalent, as well as its dependent relationship with 12 of the 17 basic human error types.

The goal of this study is to determine the patterns of human error present in rotary wing FMs. The results of this study will need to be compared with Jensen's (1999) results to determine if intervention strategies should be globally based (for entire NA) or community specific (i.e., TACAIR, rotary wing, etc.). The time period for this study will be the same as Jensen's (1999) study to permit an accurate and unbiased comparison between the results of the analyses.

III. METHODOLOGY

A. OVERVIEW

The objective of this thesis is to identify human error patterns in Naval Aviation (NA) rotary wing and tactical aircraft (TACAIR) flight mishaps (FMs), using the same analysis techniques as Jensen (1999) used for NA TACAIR FMs. The human error patterns which are identified in this thesis are compared to Jensen's (1999) results for TACAIR FMs. In addition, the data sets for rotary wing and TACAIR are combined and the analysis is repeated to determine if the same patterns of human error are present or if new patterns are recognized. This will be in an effort to determine if the intervention strategies should be applied globally for the entire NA community or if the intervention strategies should be developed for individual type aircraft communities.

B. DATA COLLECTION

The data required for this study is extracted from the Naval Safety Center's Safety Information Management System (SIMS) database. The files consist of data generated from Mishap Investigation Reports (MIRs) submitted to the Naval Safety Center (NSC) by the Aircraft Mishap Board (AMB) via message and written enclosures (Teeters, 1999). The MIRs contain an extensive narrative, which includes information of the flight mishap crews, flight mishap aircraft, and flight mishap causal factors. The MIRs for Class A FMs are very thorough, while the quality of Class B FMs vary according to the severity of the FM—the greater the damage the more thorough the investigation (Jensen, 1999). Therefore, only the Class B FMs that are thoroughly investigated will be included in this study.

In 1998, the NSC took all human factors related Class A Flight Mishaps (FM) for fiscal year (FY) 90 to FY 98 and classified them in accordance with the Human Factors Analysis and Classification System (HFACS) taxonomy (Jensen, 1999). The classification of the Class A rotary wing and TACAIR FMs by the NSC is used for this analysis. The database is also queried for all Class B human factors rotary wing and TACAIR FMs from FY 90 to FY 98 to be used in the analysis. The Class B rotary wing and TACAIR FMs are classified according to the HFACS taxonomy by CDR John Schmidt, an Aviation Psychologist at the School of Aviation Safety located in Monterey, CA, using the narrative of the MIRs description of the causal factors.

There are 54 Class A rotary wing FMs and 23 Class B rotary wing FMs, from FY 90 to FY 97 that are categorized as human factors FMs. For FY 98, there are six Class A rotary wing FMs and 2 Class B rotary wing FMs identified as human factors FMs. For Jensen's (1999) study, there are 122 Class A TACAIR FMs and 19 Class B TACAIR FMs, from FY 90 to FY 97 that are categorized as human factors FMs. For FY 98, there are 12 Class A TACAIR FMs and zero Class B TACAIR FMs identified as human factors FMs. The data for FY 98 is set aside to validate the results of the simulation model, which is constructed using FY 90 to FY 97 data.

C. PROCEDURE

The analysis is complicated by the fact that the human error types in the HFACS taxonomy have a hierarchical and dependent structure. The HFACS taxonomy allows a single FM to be given multiple causal factors; therefore, the human errors and causal factors are not mutually exclusive, which yields a very complex and conditional framework. As a result, basic statistical analysis becomes difficult and the use of simulation techniques in performing the analysis offers a more practical option. Based on original FM data and a Poisson arrival process for FMs, a simulation model is built to simulate future mishaps and predict the human error characteristics of these FMs.

The Class A and Class B FMs that are classified according to the HFACS taxonomy are entered into a Microsoft Excel 97 spreadsheet. Each row of the spreadsheet corresponds to individual FMs. The columns of the spreadsheet consist of categorical data, which includes mishap number, mishap date, model of aircraft, time of FM, mishap characteristics and a listing of all the HFACS causal factors, which are represented by 25 binary variables (one for each type of human error, see Figure 1). A "1" indicates the human error type is present in that FM and "0" if not. This puts the data in a matrix format that will allow exploratory analysis to be conducted using statistical tools such as S-Plus©.

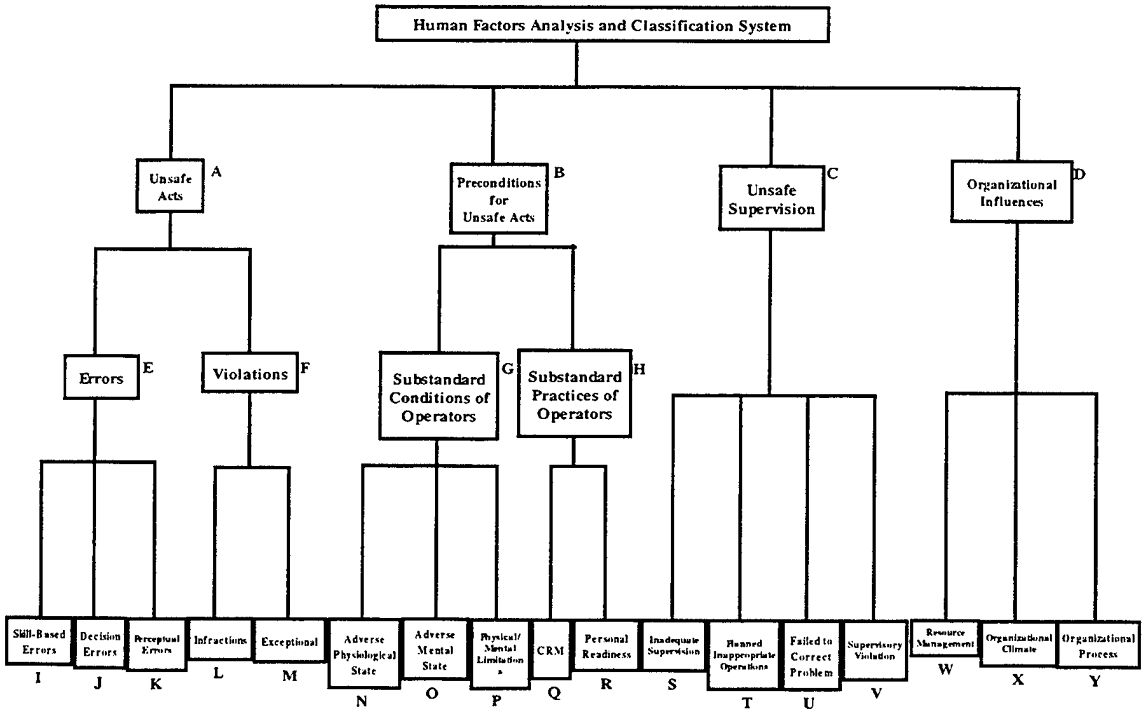

Figure 1. Hierarchical Representation of the HFACS Taxonomy The Text Next to the Causal Factor Codes the Factors A...Y to be Used During the Analysis.

D. DATA ANALYSIS

There are three basic levels in the hierarchical structure of the HFACS taxonomy, as shown in Figure 1. The lower levels are subsets of human error types contained in the upper levels. The lowest level of human error types forms the nuclei of the HFACS taxonomy, since all human error types in higher levels are composed of groupings of lower level human error types. For this reason, the majority of the analysis will be conducted on the lowest level of the HFACS taxonomy.

Statistical analysis is conducted separately for each level of the HFACS hierarchy to identify relevant causal factors and predictive patterns found in the data (Jensen, 1999). To determine any pair wise relationships, the correlation between the occurrences of causal factors for each level will be evaluated. Cluster analysis is performed to identify any important groupings of multiple human error types within each level of the HFACS taxonomy using the monothetic analysis (Mona) function in S-Plus©. Homogeneous Poisson models of the Class A and Class B rotary wing, TACAIR and combined rotary wing and TACAIR FMs occurrences is constructed using historical flight hour and

mishap data from FY 90 to FY 97 to determine the validity of the assumption of a Poisson arrival processes for FMs.

Even though the HFACS taxonomy presents a complex dependent and non-mutually exclusive collection of causal factors, a simulation in the form of bootstrapping is applied using S-Plus©. Bootstrapping allows the analysis of complicated data sets, when classical statistics fail (Lucas, 1999). The simulation model generates FMs based upon a Poisson Process, which has an arrival rate based on historical data. For each FM, the human error types are generated from the empirical distribution of the historical human error type combinations for all three data sets. These distributions are composed of all Class A and Class B rotary wing, TACAIR and combined rotary wing and TACAIR FMs from FY 90 to FY 97 and is seen as a fair representation of the distribution of human error types in each respective data set. The simulation results are compared to the FY 98 FMs.

IV. RESULTS

A. OVERVIEW

The purpose of the data analysis is to determine important relationships between the 25 causal factors in the Human Factors Analysis and Classification System (HFACS) taxonomy (see Figure 1) for rotary wing and tactical aircraft (TACAIR) Flight Mishaps (FMs) and verify that the accident arrivals for the Class A and Class B rotary wing and TACAIR FMs can be modeled as a Poisson Process (Jensen, 1999). The results are compared to the results of the analysis and modeling for the Class A and Class B TACAIR FMs in Jensen's (1999) study. When the TACAIR FMs were entered into Microsoft Excel 97 spreadsheet, the totals for the causal factors did not exactly match Jensen's (1999) study, which is due to the fact that the data was obtained from the Naval Safety Center at different times. Therefore, the analysis for the TACAIR FMs is repeated in this analysis. The data used for the analysis are 77 Class A and B rotary wing FMs and 141 Class A and B TACAIR FMs between fiscal year (FY) 90 and FY 97 that cited human error as the primary causal factor. FMs due entirely to mechanical or maintenance human error are excluded. The rotary wing and TACAIR Class A and B FMs for FY 98 are set aside to validate the FM rate of the models.

B. EXPLORATORY DATA ANALYSIS OF CAUSAL FACTORS

Classifying the FMs according to the HFACS taxonomy (see Figure 1) is represented as a binary row vector of "1's" and "0's" for each FM (Jensen, 1999). A "1" indicates that the causal factor is cited in the FM, whereas a "0" indicates that the causal factor is not cited in the FM. When these binary row vectors are combined, the result is a binary asymmetric matrix X. The causal factors are defined as sets, which are subsets of the FMs that cited that causal factor (see Table 1). Exploratory data analysis is achieved by analyzing the relationship between these sets.

1. Notation and Data Structure

The notation and data structure for the analysis is identical to the analysis of Jensen's (1999) study, with the addition of a subscript H for rotary wing, T for TACAIR and C for the combined rotary wing and TACAIR data sets. For the initial exploratory data analysis, the causal factors correspond to the sets of FMs that cite that causal factor as defined in Table 1. The relationships between the sets are defined as:

$$(A \cup B \cup C \cup D) = XX, \quad (1)$$

$$(E \cup F) = A, \quad (2)$$

$$(G \cup H) = B, \quad (3)$$

$$(S \cup T \cup U \cup V) = C, \quad (4)$$

$$(W \cup X \cup Y) = D, \quad (5)$$

$$(I \cup J \cup K) = E, \quad (6)$$

$$(L \cup M) = F, \quad (7)$$

$$(N \cup O \cup P) = G, \quad (8)$$

$$(Q \cup R) = H, \quad (9)$$

It is evident that the sets of equations (1) through (9) are not mutually exclusive. In fact equations (1) through (9) demonstrate a hierarchical relationship between these sets and this relationship is visually represented in Figure 1. The causal factors at the bottom of the HFACS taxonomy in Figure 1 correspond to the most basic human error types. Through this relationship, analysis is focused on the most basic human error types to infer the findings at the most basic level of human error types to the higher levels. The basic human error types are considered subsets of the human error types defined by the causal factors in the higher levels. For example, see equation (7), human error type F (Violation) contains all FMs that cited either human error type L (Infraction) or M (Exceptional) or both.

Three classes of sets are constructed for rotary wing, TACAIR and the combined FMs data sets using the existing subset relationship. Each class represents a level of classification in the HFACS taxonomy structure. The first class, $HFACSA_H$, $HFACSA_T$ and $HFACSA_C$ is built from the top level sets, which include sets A, B, C and D (see Figure 1). The second class, $HFACSB_H$, $HFACSB_T$ and $HFACSB_C$ is built from the middle level sets, which include sets E, F, G, H, C and D (see Figure 1). The final class, $HFACSC_H$, $HFACSC_T$ and $HFACSC_C$ is built from the bottom level sets, which include sets I,...,Y (see Figure 1). Appendix A contains a key for human error types coding (see Table A1).

Table 1. Set Definitions for HFACS Sets A...Y and the Universal Set XX.

Set Definitions:		
XX	=	{all human factors Class A & B FMs from FY90 to FY97, excluding Those FMs attributable to mechanical or maintenance human factors}
A	=	{xx|xx cited as a causal factor Unsafe Acts}
B	=	{xx|xx cited as a causal factor Preconditions for Unsafe Acts}
C	=	{xx|xx cited as a causal factor Unsafe Supervision}
D	=	{xx|xx cited as a causal factor Organizational Influences}
E	=	{xx|xx cited as a causal factor Errors}
F	=	{xx|xx cited as a causal factor Violations}
G	=	{xx|xx cited as a causal factor Substandard Conditions of Operators}
H	=	{xx|xx cited as a causal factor Substandard Practices of Operators}
I	=	{xx|xx cited as a causal factor Skill-Based Errors}
J	=	{xx|xx cited as a causal factor Decision Errors}
K	=	{xx|xx cited as a causal factor Perceptual Errors}
L	=	{xx|xx cited as a causal factor Infraction}
M	=	{xx|xx cited as a causal factor Exceptional}
N	=	{xx|xx cited as a causal factor Adverse Physiological State}
O	=	{xx|xx cited as a causal factor Adverse Mental State}
P	=	{xx|xx cited as a causal factor Physical/Mental Limitation}
Q	=	{xx|xx cited as a causal factor Crew Resource Management (CRM)}
R	=	{xx|xx cited as a causal factor Personal Readiness}
S	=	{xx|xx cited as a causal factor Inadequate Supervision}
T	=	{xx|xx cited as a causal factor Planned Inappropriate Operations}
U	=	{xx|xx cited as a causal factor Failed to Correct Problem}
V	=	{xx|xx cited as a causal factor Supervisory Violation}
W	=	{xx|xx cited as a causal factor Resource Management}
X	=	{xx|xx cited as a causal factor Organizational Climate}
Y	=	{xx|xx cited as a causal factor Organizational Process}

An alternative way of defining these classes is by identifying them with the matrix X defined at the beginning of Chapter IV. X_H (rotary wing) is a 77x25 matrix, X_T (TACAIR) is a 141x25 matrix and X_C (combination) is a 218x25 matrix with all HFACS human error types defining the columns and FMs between FY 90 and FY 97 defining the rows for each particular matrix. The first class corresponds to the four columns of X_H, X_T, and X_C which are indicators for sets A, B, C and D, for each respective matrix. Extracting these four columns from each matrix gives a 77x4 matrix for X_H, a 141x4 matrix for X_T and a 218x4 matrix for X_C, which is equivalent to the first class and define the matrices X_{HA}, X_{TA} and X_{CA}. The second class corresponds to the respective column vectors E, F, G, H, C, and D of X_H, X_T and X_C. Extracting these six columns from each matrix gives a 77x6 matrix for X_H, a 141x6 matrix for X_T and a 218x6 matrix for X_C, which is equivalent to the second class and define the matrices X_{HB}, X_{TB} and X_{CB}. The third class corresponds to the respective column vectors I,...,Y of X_H, X_T and X_C. Extracting these 17 columns

from each matrix gives a 77x17 matrix for X_H, a 141x17 matrix for X_T and a 218x17 matrix for X_C, which is equivalent to the third class and define the matrices X_{HC}, X_{TC} and X_{CC}.

All FMs contained in the classes $HFACSA_H$, $HFACSB_H$, $HFACSC_H$, $HFACSA_T$, $HFACSB_T$, $HFACSC_T$, $HFACSA_C$, $HFACSB_C$, and $HFACSC_C$ are also contained in their respective matrices X_{HA}, X_{HB}, X_{HC}, X_{TA}, X_{TB}, X_{TC}, X_{CA}, X_{CB}, and X_{CC} along with the corresponding FM causal factors. It is important to note that none of the sets contained in the classes or matrices are mutually exclusive, which means a single FM may belong to different sets. For this reason, there are multiple dependent relationships between the various human error types. As a result, analysis using simple probability of a causal factor occurrence is not feasible in the exploration of relationships in the HFACS taxonomy.

2. Analysis of Pairwise Dependency

To take an initial look at the relationship between the human error types, correlation matrices are calculated for the columns of X_{HA}, X_{HB}, X_{HC}, X_{TA}, X_{TB}, X_{TC}, X_{CA}, X_{CB}, and X_{CC}. The correlation matrices are located in Appendix B (see Tables B1 through B9). For rotary wing, the highest correlation of all three matrices is in the matrix X_{HC} between set N (Adverse Physiological State) and set K (Perceptual Errors) with a correlation of .73. The next highest correlation is .48 between sets A (Unsafe Acts) and B (Preconditions for Unsafe Acts) in the matrix X_{HA}. Otherwise, all other correlations range between -.404 and .433 for all three matrices. When examining the accident data, the relationships between sets N and K address only 14, or 18%, of the FMs (see Table 2), while sets A and B address 69, or 90%, of the FMs. Sets A and B appear to be significant; however, set B addresses human error types which exhibit "Preconditions for Unsafe Acts" and set A addresses human error types that include "Unsafe Acts." Therefore, a high correlation between these human error types is expected.

For TACAIR, the highest correlation of all three matrices is in the matrix X_{TC} between set N (Adverse Physiological State) and set K (Perceptual Errors) with a correlation of .601. The next highest correlation is .386 between sets U (Failed to Correct Problem) and V (Supervisory Violation) in the matrix X_{TC}. Otherwise, all other correlations range between -.297 and .345 for all three matrices. When examining the

accident data, the relationships between sets N and K address only 22, or 16%, of the FMs (see Table 3), while sets U and V address 4, or 3%, of the FMs (see Table 3). Therefore, these sets possess only a mild positive relationship.

For the combined data set, the highest correlation of all three matrices is in the matrix X_{CC} between set N (Adverse Physiological State) and set K (Perceptual Errors) with a correlation of .646. The next highest correlation is -.254 between sets E (Errors) and F (Violations) in the matrix X_{CB}. Otherwise, all other correlations range between -.248 and .241 for all three matrices. When examining the accident data, the relationships between sets N and K address only 36, or 17%, of the FMs (see Table 4), while sets E and F address 65, or 30%, of the FMs. Therefore, these sets possess only a mild relationship.

The emphasis in this study's analysis will now concentrate on the class $\mathrm{HFACSC_H}$ (X_{HC}), $\mathrm{HFACSC_T}$ (X_{TC}) and $\mathrm{HFACSC_C}$ (X_{CC}). The reason is that this class consists of the most basic forms of human error types and it is an exhaustive listing of human error types associated with NA. In addition, all the sets in the classes $\mathrm{HFACSC_H}$ (X_{HC}), $\mathrm{HFACSC_T}$ ($\mathrm{X_{TC}}$) and $\mathrm{HFACSC_C}$ (X_{CC}) are subsets of the respective sets in the classes $\mathrm{HFACSA_H}$ (X_{HA}), $\mathrm{HFACSB_H}$ (X_{HB}), $\mathrm{HFACSA_T}$ (X_{TA}), $\mathrm{HFACSB_T}$ (X_{TB}), $\mathrm{HFACSA_C}$ (X_{AC}) and $\mathrm{HFACSB_C}$ (X_{CB}), as defined in set equations (1) through (9). Therefore, this study can concentrate on the human error types of $\mathrm{HFACSC_H}$ (X_{HC}), $\mathrm{HFACSC_T}$ (X_{TC}) and $\mathrm{HFACSC_C}$ (X_{CC}) classes without loss of generality (Jensen, 1999).

The first step of the exploratory analysis is to create the matrices that define the number of rotary wing, TACAIR, and combined rotary wing and TACAIR FMs that cite a specific human error type and combinations of human error types (see Table 2, 3 & 4).

$$\mathrm{M_{HC}} = (\mathrm{X_{HC}})^{\mathrm{T}} (\mathrm{X_{HC}}) \qquad (10)$$

$$\mathrm{M_{TC}} = (\mathrm{X_{TC}})^{\mathrm{T}} (\mathrm{X_{TC}}) \qquad (11)$$

$$\mathrm{M_{CC}} = (\mathrm{X_{CC}})^{\mathrm{T}} (\mathrm{X_{CC}}) \qquad (12)$$

The rows and columns of $\mathrm{M_{HC}}$, $\mathrm{M_{TC}}$ and $\mathrm{M_{CC}}$ are indexed by i, j= I,...,Y. Let each $m_{hc}(i,j)$ be the number of rotary wing FMs in the intersection of sets i and j, $m_{tc}(i,j)$ be the number of TACAIR FMs in the intersection of sets i and j, and $m_{cc}(i,j)$ be the number of rotary wing and TACAIR FMs in the intersection of sets i and j. Whereas, set i is defined by $m_{hc}(i,i)$, $m_{tc}(i,i)$ and $m_{cc}(i,i)$, which represent the number of rotary wing, TACAIR and

combination FMs that cite human error of type “i” as a causal factor, respectively. For example, $m_{hc}(O,Q) = 42$ (see Table 2), represents the number of rotary wing FMs in the intersection of sets O and Q, so 42 FMs between FY 90 and FY 97 cited both human error types O and Q as causal factors.

Table 2. Matrix M_{HC}, Depicting the Number of Rotary Wing FMs Between FY 90 and FY 97 that Contain an Individual Set or Intersecting Sets of Causal Factors.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	38	21	7	11	5	5	26	3	29	0	12	5	2	3	7	0	11
J		45	14	11	5	9	27	5	34	1	14	5	0	4	10	0	12
K			21	6	5	14	15	2	17	0	6	4	1	3	6	0	5
L				20	4	6	16	3	15	1	13	4	4	2	2	0	6
M					15	3	13	0	15	1	7	2	5	4	3	0	5
N						15	13	1	12	0	4	3	2	1	6	0	5
O							53	3	42	1	16	9	7	6	10	0	15
P								6	4	0	4	0	0	1	1	0	2
Q									57	2	19	9	7	6	10	0	14
R										2	0	1	1	1	0	0	1
S											24	4	5	2	2	0	5
T												10	2	2	2	0	3
U													8	1	0	0	3
V														7	2	0	4
W															16	0	7
X																0	0
Y																	20

The proportion matrices P_{HC}, P_{TC} and P_{CC} represent the proportions for the pairwise intersections of human error types of rotary wing, TACAIR and combined rotary wing and TACAIR FMs (see Tables 5, 6 & 7). Let,

$$P_{HC} = m_{hc}(i,j) / 77 \qquad \forall i,j, \qquad (13)$$

$$P_{TC} = m_{tc}(i,j) / 141 \qquad \forall i,j, \qquad (14)$$

$$P_{CC} = m_{cc}(i,j) / 218 \qquad \forall i,j, \qquad (15)$$

where 77, 141 and 218 represent the total number of rotary wing, TACAIR and combined rotary wing and TACAIR FMs in FY 90 to FY 97, respectively. The diagonal of these matrices, gives $P_{HC}(i)$, $P_{TC}(i)$ and $P_{CC}(i)$, which represent the proportion of FMs that cite causal factor “i” to the total number of rotary wing, TACAIR and combined rotary wing and TACAIR FMs studied (see Tables 5, 6 & 7). The remaining cells of the matrices

represent $P_{HC}(i \cap j)$, $P_{TC}(i \cap j)$ and $P_{CC}(i \cap j)$, which are the proportion of the total FMs citing human error type "i" and "j" in combination to the total number of FMs studied for each respective matrix (see Tables 5, 6 & 7). It is important to note that $P_{HC}(i , i)$ or the proportion of FMs with human error type "i" is not the sum of $P_{HC}(i , j)$ for all j, because of the non-mutually exclusive nature of HFACS. The same relationship holds for the TACAIR and the combined rotary wing and TACAIR proportion matrices (P_{TC} & P_{CC}).

Table 3. Matrix M_{TC}, Depicting the Number of TACAIR FMs Between FY 90 and FY 97 that Contain an Individual Set or Intersecting Sets of Causal Factors.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	86	38	15	14	6	17	63	6	43	4	19	8	6	9	23	1	25
J		76	13	16	13	12	50	1	45	3	19	10	6	8	21	0	26
K			35	12	8	22	27	2	13	4	9	3	3	2	9	1	8
L				29	5	9	17	1	12	2	7	1	4	3	5	1	7
M					22	5	10	2	10	2	3	2	1	1	4	1	2
N						29	23	2	10	3	7	2	3	2	9	1	9
O							94	7	46	6	24	13	8	9	27	1	29
P								8	5	1	1	0	1	1	3	0	2
Q									67	2	15	6	4	5	14	1	19
R										7	4	1	1	1	0	0	2
S											33	7	3	5	8	0	11
T												14	0	1	4	0	5
U													8	4	3	1	2
V														11	5	0	3
W															39	0	16
X																1	0
Y																	42

Table 4. Matrix M_{CC}, Depicting the Number of Combined Rotary Wing and TACAIR FMs Between FY 90 to FY 97 that Contain Individual Set or Intersecting Sets of Causal Factors.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	124	59	22	25	11	22	89	9	72	4	31	13	8	12	30	1	36
J		121	27	27	18	21	77	6	79	4	33	15	6	12	31	0	38
K			56	18	13	36	42	4	30	4	15	7	4	5	15	1	13
L				49	9	15	33	4	27	3	20	5	8	5	7	1	13
M					37	8	23	2	25	3	10	4	6	5	7	1	7
N						44	36	3	22	3	11	5	5	3	15	1	14
O							147	10	88	7	40	22	15	15	37	1	44
P								14	9	1	5	0	1	2	4	0	4
Q									124	4	34	15	11	11	24	1	33
R										9	4	2	2	2	0	0	3
S											57	11	8	7	10	0	16
T												24	2	3	6	0	8
U													16	5	3	1	5
V														18	7	0	7
W															55	0	23
X																1	0
Y																	62

Table 5. Matrix P_{HC}, Depicting the Proportion of Rotary Wing FMs Between FY 90 and FY 97 that Contain an Individual Set or Intersecting Sets of Causal Factors.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	0.49	0.27	0.09	0.14	0.06	0.06	0.34	0.04	0.38	0.00	0.16	0.06	0.03	0.04	0.09	0.00	0.14
J		0.58	0.18	0.14	0.06	0.12	0.35	0.06	0.44	0.01	0.18	0.06	0.00	0.05	0.13	0.00	0.16
K			0.27	0.08	0.06	0.18	0.19	0.03	0.22	0.00	0.08	0.05	0.01	0.04	0.08	0.00	0.06
L				0.26	0.05	0.08	0.21	0.04	0.19	0.01	0.17	0.05	0.05	0.03	0.03	0.00	0.08
M					0.19	0.04	0.17	0.00	0.19	0.01	0.09	0.03	0.06	0.05	0.04	0.00	0.06
N						0.19	0.17	0.01	0.16	0.00	0.05	0.04	0.03	0.01	0.08	0.00	0.06
O							0.69	0.04	0.55	0.01	0.21	0.12	0.09	0.08	0.13	0.00	0.19
P								0.08	0.05	0.00	0.05	0.00	0.00	0.01	0.01	0.00	0.03
Q									0.74	0.03	0.25	0.12	0.09	0.08	0.13	0.00	0.18
R										0.03	0.00	0.01	0.01	0.01	0.00	0.00	0.01
S											0.31	0.05	0.06	0.03	0.03	0.00	0.06
T												0.13	0.03	0.03	0.03	0.00	0.04
U													0.10	0.01	0.00	0.00	0.04
V														0.09	0.03	0.00	0.05
W															0.21	0.00	0.09
X																0.00	0.00
Y																	0.26

Table 6. Matrix P_{HC}, Depicting the Proportion of Rotary Wing FMs Between FY 90 and FY 97 that Contain an Individual Set or Intersecting Sets of Causal Factors.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	0.61	0.27	0.11	0.10	0.04	0.12	0.45	0.04	0.30	0.03	0.13	0.06	0.04	0.06	0.16	0.01	0.18
J		0.54	0.09	0.11	0.09	0.09	0.35	0.01	0.32	0.02	0.13	0.07	0.04	0.06	0.15	0.00	0.18
K			0.25	0.09	0.06	0.16	0.19	0.01	0.09	0.03	0.06	0.02	0.02	0.01	0.06	0.01	0.06
L				0.21	0.04	0.06	0.12	0.01	0.09	0.01	0.05	0.01	0.03	0.02	0.04	0.01	0.05
M					0.16	0.04	0.07	0.01	0.07	0.01	0.02	0.01	0.01	0.01	0.03	0.01	0.01
N						0.21	0.16	0.01	0.07	0.02	0.05	0.01	0.02	0.01	0.06	0.01	0.06
O							0.67	0.05	0.33	0.04	0.17	0.09	0.06	0.06	0.19	0.01	0.21
P								0.06	0.04	0.01	0.01	0.00	0.01	0.01	0.02	0.00	0.01
Q									0.48	0.01	0.11	0.04	0.03	0.04	0.10	0.01	0.13
R										0.05	0.03	0.01	0.01	0.01	0.00	0.00	0.01
S											0.23	0.05	0.02	0.04	0.06	0.00	0.08
T												0.10	0.00	0.01	0.03	0.00	0.04
U													0.06	0.03	0.02	0.01	0.01
V														0.08	0.04	0.00	0.02
W															0.28	0.00	0.11
X																0.01	0.00
Y																	0.30

Table 7. Matrix P_{CC}, Depicting the Proportion of the Combined Rotary Wing and TACAIR FMs Between FY 90 and FY 97 that Contain an Individual Set or Intersecting Sets of Causal Factors.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	0.57	0.27	0.10	0.11	0.05	0.10	0.41	0.04	0.33	0.02	0.14	0.06	0.04	0.06	0.14	0.00	0.17
J		0.56	0.12	0.12	0.08	0.10	0.35	0.03	0.36	0.02	0.15	0.07	0.03	0.06	0.14	0.00	0.17
K			0.26	0.08	0.06	0.17	0.19	0.02	0.14	0.02	0.07	0.03	0.02	0.02	0.07	0.00	0.06
L				0.22	0.04	0.07	0.15	0.02	0.12	0.01	0.09	0.02	0.04	0.02	0.03	0.00	0.06
M					0.17	0.04	0.11	0.01	0.11	0.01	0.05	0.02	0.03	0.02	0.03	0.00	0.03
N						0.20	0.17	0.01	0.10	0.01	0.05	0.02	0.02	0.01	0.07	0.00	0.06
O							0.67	0.05	0.40	0.03	0.18	0.10	0.07	0.07	0.17	0.00	0.20
P								0.06	0.04	0.00	0.02	0.00	0.00	0.01	0.02	0.00	0.02
Q									0.57	0.02	0.16	0.07	0.05	0.05	0.11	0.00	0.15
R										0.04	0.02	0.01	0.01	0.01	0.00	0.00	0.01
S											0.26	0.05	0.04	0.03	0.05	0.00	0.07
T												0.11	0.01	0.01	0.03	0.00	0.04
U													0.07	0.02	0.01	0.00	0.02
V														0.08	0.03	0.00	0.03
W															0.25	0.00	0.11
X																0.00	0.00
Y																	0.28

To effectively examine the relationships between human error types, we must look at the conditional proportions for the intersections of human error sets for the rotary wing, TACAIR and the combined rotary wing and TACAIR FMs. These relationships are displayed in the S_{HC}, S_{TC} and S_{CC} matrices, where

$$S_{HC} = m_{hc}(i,j) \,/\, m_{hc}(i,i) \qquad \forall i,j, \qquad (16)$$

$$S_{TC} = m_{tc}(i,j) \,/\, m_{tc}(i,i) \qquad \forall i,j, \qquad (17)$$

$$S_{CC} = m_{cc}(i,j) \,/\, m_{cc}(i,i) \qquad \forall i,j. \qquad (18)$$

The entries of the matrices give the proportion of FMs that cite a specific causal factor given that FM also cites another causal factor (see Tables 8, 9 & 10). In order to read the relationship correctly, read the column causal factor then the row causal factor. For example, at the S_{HC} matrix's (see Table 8) cell (O, N), 87 percent of the time given an FM cites human error type N (Adverse Physiological State) as a causal factor, that FM will also cite human error type O (Adverse Mental State) as a causal factor.

Table 8. Matrix S_{HC}, Depicting the Conditional Proportions for Rotary Wing FMs Between FY 90 and FY 97.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I		0.47	0.33	0.55	0.33	0.33	0.49	0.50	0.51	0.00	0.50	0.50	0.25	0.43	0.44		0.55
J	0.55		0.67	0.55	0.33	0.60	0.51	**0.83**	0.60	0.50	0.58	0.50	0.00	0.57	0.63		0.60
K	0.18	0.31		0.30	0.33	**0.93**	0.28	0.33	0.30	0.00	0.25	0.40	0.13	0.43	0.38		0.25
L	0.29	0.24	0.29		0.27	0.40	0.30	0.50	0.26	0.50	0.54	0.40	0.50	0.29	0.13		0.30
M	0.13	0.11	0.24	0.20		0.20	0.25	0.00	0.26	0.50	0.29	0.20	0.63	0.57	0.19		0.25
N	0.13	0.20	0.67	0.30	0.20		0.25	0.17	0.21	0.00	0.17	0.30	0.25	0.14	0.38		0.25
O	0.68	0.60	**0.71**	**0.80**	**0.87**	**0.87**		0.50	**0.74**	0.50	0.67	**0.90**	**0.88**	**0.86**	0.63		**0.75**
P	0.08	0.11	0.10	0.15	0.00	0.07	0.06		0.07	0.00	0.17	0.00	0.00	0.14	0.06		0.10
Q	**0.76**	**0.76**	**0.81**	**0.75**	**1.00**	**0.80**	**0.79**	0.67		1.00	**0.79**	**0.90**	**0.88**	**0.86**	0.63		**0.70**
R	0.00	0.02	0.00	0.05	0.07	0.00	0.02	0.00	0.04		0.00	0.10	0.13	0.14	0.00		0.05
S	0.32	0.31	0.29	0.65	0.47	0.27	0.30	0.67	0.33	0.00		0.40	0.63	0.29	0.13		0.25
T	0.13	0.11	0.19	0.20	0.13	0.20	0.17	0.00	0.16	0.50	0.17		0.25	0.29	0.13		0.15
U	0.05	0.00	0.05	0.20	0.33	0.13	0.13	0.00	0.12	0.50	0.21	0.20		0.14	0.00		0.15
V	0.08	0.09	0.14	0.10	0.27	0.07	0.11	0.17	0.11	0.50	0.08	0.20	0.13		0.13		0.20
W	0.18	0.22	0.29	0.10	0.20	0.40	0.19	0.17	0.18	0.00	0.08	0.20	0.00	0.29			0.35
X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Y	0.29	0.27	0.24	0.30	0.33	0.33	0.28	0.33	0.25	0.50	0.21	0.30	0.38	0.57	0.44		

Note: To read the relationship correctly, read column to row.

Table 9. Matrix S_{TC}, Depicting the Conditional Proportions for TACAIR FMs Between FY 90 and FY 97.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I		0.50	0.43	0.48	0.27	0.59	0.67	**0.75**	0.64	0.57	0.58	0.57	**0.75**	**0.82**	0.59	1.00	0.60
J	0.44		0.37	0.55	0.59	0.41	0.53	0.13	0.67	0.43	0.58	**0.71**	**0.75**	**0.73**	0.54	0.00	0.62
K	0.17	0.17		0.41	0.36	**0.76**	0.29	0.25	0.19	0.57	0.27	0.21	0.38	0.18	0.23	1.00	0.19
L	0.16	0.21	0.34		0.23	0.31	0.18	0.13	0.18	0.29	0.21	0.07	0.50	0.27	0.13	1.00	0.17
M	0.07	0.17	0.23	0.17		0.17	0.11	0.25	0.15	0.29	0.09	0.14	0.13	0.09	0.10	1.00	0.05
N	0.20	0.16	0.63	0.31	0.23		0.24	0.25	0.15	0.43	0.21	0.14	0.38	0.18	0.23	1.00	0.21
O	**0.73**	0.66	**0.77**	0.59	0.45	**0.79**		**0.88**	0.69	**0.86**	**0.73**	**0.93**	**1.00**	**0.82**	0.69	1.00	0.69
P	0.07	0.01	0.06	0.03	0.09	0.07	0.07		0.07	0.14	0.03	0.00	0.13	0.09	0.08	0.00	0.05
Q	0.50	0.59	0.37	0.41	0.45	0.34	0.49	0.63		0.29	0.45	0.43	0.50	0.45	0.36	1.00	0.45
R	0.05	0.04	0.11	0.07	0.09	0.10	0.06	0.13	0.03		0.12	0.07	0.13	0.09	0.00	0.00	0.05
S	0.22	0.25	0.26	0.24	0.14	0.24	0.26	0.13	0.22	0.57		0.50	0.38	0.45	0.21	0.00	0.26
T	0.09	0.13	0.09	0.03	0.09	0.07	0.14	0.00	0.09	0.14	0.21		0.00	0.09	0.10	0.00	0.12
U	0.07	0.08	0.09	0.14	0.05	0.10	0.09	0.13	0.06	0.14	0.09	0.00		0.36	0.08	1.00	0.05
V	0.10	0.11	0.06	0.10	0.05	0.07	0.10	0.13	0.07	0.14	0.15	0.07	0.50		0.13	0.00	0.07
W	0.27	0.28	0.26	0.17	0.18	0.31	0.29	0.38	0.21	0.00	0.24	0.29	0.38	0.45		0.00	0.38
X	0.01	0.00	0.03	0.03	0.05	0.03	0.01	0.00	0.01	0.00	0.00	0.00	0.13	0.00	0.00		0.00
Y	0.29	0.34	0.23	0.24	0.09	0.31	0.31	0.25	0.28	0.29	0.33	0.36	0.25	0.27	0.41	0.00	

Note: To read the relationship correctly, read column to row.

Table 10. Matrix S_{CC}, Depicting the Conditional Proportions for Combined Rotary Wing and TACAIR FMs Between FY 90 and FY 97.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I		0.49	0.39	0.51	0.30	0.50	0.61	0.64	0.58	0.44	0.54	0.54	0.50	0.67	0.55	1.00	0.58
J	0.48		0.48	0.55	0.49	0.48	0.52	0.43	0.64	0.44	0.58	0.63	0.38	0.67	0.56	0.00	0.61
K	0.18	0.22		0.37	0.35	**0.82**	0.29	0.29	0.24	0.44	0.26	0.29	0.25	0.28	0.27	1.00	0.21
L	0.20	0.22	0.32		0.24	0.34	0.22	0.29	0.22	0.33	0.35	0.21	0.50	0.28	0.13	1.00	0.21
M	0.09	0.15	0.23	0.18		0.18	0.16	0.14	0.20	0.33	0.18	0.17	0.38	0.28	0.13	1.00	0.11
N	0.18	0.17	0.64	0.31	0.22		0.24	0.21	0.18	0.33	0.19	0.21	0.31	0.17	0.27	1.00	0.23
O	**0.72**	0.64	**0.75**	0.67	0.62	**0.82**		**0.71**	**0.71**	**0.78**	**0.70**	**0.92**	**0.94**	**0.83**	0.67	1.00	**0.71**
P	0.07	0.05	0.07	0.08	0.05	0.07	0.07		0.07	0.11	0.09	0.00	0.06	0.11	0.07	0.00	0.06
Q	0.58	0.65	0.54	0.55	0.68	0.50	0.60	0.64		0.44	0.60	0.63	0.69	0.61	0.44	1.00	0.53
R	0.03	0.03	0.07	0.06	0.08	0.07	0.05	0.07	0.03		0.07	0.08	0.13	0.11	0.00	0.00	0.05
S	0.25	0.27	0.27	0.41	0.27	0.25	0.27	0.36	0.27	0.44		0.46	0.50	0.39	0.18	0.00	0.26
T	0.10	0.12	0.13	0.10	0.11	0.11	0.15	0.00	0.12	0.22	0.19		0.13	0.17	0.11	0.00	0.13
U	0.06	0.05	0.07	0.16	0.16	0.11	0.10	0.07	0.09	0.22	0.14	0.08		0.28	0.05	1.00	0.08
V	0.10	0.10	0.09	0.10	0.14	0.07	0.10	0.14	0.09	0.22	0.12	0.13	0.31		0.13	0.00	0.11
W	0.24	0.26	0.27	0.14	0.19	0.34	0.25	0.29	0.19	0.00	0.18	0.25	0.19	0.39		0.00	0.37
X	0.01	0.00	0.02	0.02	0.03	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.06	0.00	0.00		0.00
Y	0.29	0.31	0.23	0.27	0.19	0.32	0.30	0.29	0.27	0.33	0.28	0.33	0.31	0.39	0.42	0.00	

Note: To read the relationship correctly, read column to row.

To identify the important conditional proportions in the S_{HC}, S_{TC} and S_{CC} matrices (see Tables 8, 9 & 10), a floor of 70 percent is set for a particular relationship to be considered in further analysis. For the S_{HC} matrix (see Table 8), there are 23 sets which meet the 70 percent criteria (entries in the R and X columns are not considered since they only represent two and zero FMs, respectively, and do not provide insight into other FMs). For the S_{TC} matrix (see Table 9), there are 16 sets which meet the 70 percent criteria (entries in the X column are not considered since they only represent one FM and do not provide insight into other FMs). For the S_{CC} matrix (see Table 10), there are 12 sets which meet the 70 percent criteria (entries in the X column are not considered since they only represent one FM and do not provide insight into other FMs). These sets are displayed in Table 11.

For the rotary wing FMs, the most noticeable combinations contain human error type Q (Crew Resource Management) the largest proportion of the time, 12 of the 23 combinations in Table 11. Also, human error type O (Adverse Mental State) appears a considerable proportion of the time, 9 of the 23 combinations in Table 11. For TACAIR FMs, the most noticeable combinations contain human error type O (Adverse Mental State) the largest proportion of the time, 9 of the 16 combinations in Table 11. For the combined data set, human error type O (Adverse Mental State) occurs in 11 of the 12 combinations in Table 11. To explore these stronger relationships found in the analysis and listed in Table 11, cluster analysis is performed to determine the combinations of these strong relationships. Also, a simulation model is constructed based on the Poisson distribution of the data sets to predict the characteristics and occurrences of future human error in NA rotary wing and TACAIR FMs.

Table 11. Important Subsets of Human Error Causal Factors Extracted from Tables 8, 9 and 10.

	Rotary Wing	TACAIR	Combined Rotary Wing and TACAIR
Relationships	Percentage	Percentage	Percentage
$M \subset Q$	100	-	-
$N \subset K$	93	76	82
$T \subset O$	90	93	92
$T \subset Q$	90	-	-
$U \subset O$	88	100	94
$U \subset Q$	88	-	-
$M \subset O$	87	-	-
$N \subset O$	87	79	82
$V \subset O$	86	82	83
$V \subset Q$	86	-	-
$P \subset J$	83	-	-
$K \subset Q$	81	-	-
$L \subset O$	80	-	-
$N \subset Q$	80	-	-
$O \subset Q$	79	-	-
$S \subset Q$	79	-	-
$I \subset Q$	76	-	-
$J \subset Q$	76	-	-
$Y \subset O$	75	-	71
$L \subset Q$	75	-	-
$Q \subset O$	74	-	71
$K \subset O$	71	77	75
$Y \subset Q$	70	-	-
$P \subset O$	-	88	71
$R \subset O$	-	86	78
$V \subset I$	-	82	-
$P \subset I$	-	75	-
$U \subset I$	-	75	-
$U \subset J$	-	75	-
$I \subset O$	-	73	72
$S \subset O$	-	73	70
$V \subset J$	-	73	-
$T \subset J$	-	71	-

3. Cluster Analysis

Cluster analysis of the data is performed using a monothetic divisive algorithm, which produces a hierarchy of clusters (Kaufman & Rousseeuw, 1990). The binary asymmetric structure of HFACS permits this method to divide the data set into subsets using a single binary variable vice all of the variables simultaneously. This method is applied to all nine sets of classes—$HFACSA_H$, $HFACSB_H$, $HFACSC_H$, $HFACSA_T$,

$HFACSB_T$, $HFACSC_T$, $HFACSA_C$, $HFACSB_C$, and $HFACSC_C$, using the function MONA in S-Plus© with the following results:

1) $HFACSA_H$ with four sets has 2^4 combinations and it clusters into seven separate combinations.

2) $HFACSB_H$ with six sets has 2^6 combinations and it clusters into 27 separate combinations.

3) $HFACSC_H$ with 17 sets has 2^{17} combinations and it clusters into 67 separate combinations.

4) $HFACSA_T$ with four sets has 2^4 combinations and it clusters into eight separate combinations.

5) $HFACSB_T$ with six sets has 2^6 combinations and it clusters into 33 separate combinations.

6) $HFACSC_T$ with 17 sets has 2^{17} combinations and it clusters into 121 separate combinations.

7) $HFACSA_C$ with four sets has 2^4 combinations and it clusters into nine separate combinations.

8) $HFACSB_C$ with six sets has 2^6 combinations and it clusters into 38 separate combinations.

9) $HFACSC_C$ with 17 sets has 2^{17} combinations and it clusters into 174 separate combinations.

For $HFACSC_H$, the 67 combinations used by MONA cover 77 accidents, 8 combinations share multiple accidents, while 59 accidents are unique combinations. For $HFACSC_T$, the 121 combinations used by MONA cover 141 accidents, 13 combinations share multiple accidents, while 108 accidents are unique combinations. For $HFACSC_C$, the 174 combinations used by MONA cover 218 accidents, 27 combinations share multiple accidents, while 147 accidents are unique combinations. See Table 12 for the multiple accident listings of the causal factor combinations.

Within the cluster analysis of all three of the lowest level classes—$HFACSC_H$, $HFACSC_T$, and $HFACSC_C$, four factors are dominant in the accident combinations. These four factors are O (Adverse Mental State), Q (Crew Resource Management), I (Skill-Based Errors) and J (Decision Errors). For rotary wing, human error of type Q (Crew

Resource Management) is the most dominant causal factor and is present in 8 of the 15 important combinations identified (see Table 13). Also, as seen in Table 13 for rotary wing, human error of type O (Adverse Mental State) is a significant causal factor, since it is present in 7 of the 15 important combinations identified. The results of the important combinations from the cluster analysis for the TACAIR and the combined rotary wing and TACAIR data set are identical. The human error of type O (Adverse Mental State) is present in 7 of the 10 important combinations identified (see Table 13).

Table 12. Combinations of Causal Factors Common to More Than One FM.

Number of Accidents	Combination of Causal Factors		
	Rotary Wing	TACAIR	Combined Rotary Wing and TACAIR
2	M, O, Q, S, U I, L, O, Q I, J, Q I, J, O, Q J, O, Q, W J, Q, W, Y K, N, O, Q	I I, O, W, Y I, O, Q I, O, Q, W I, J, Q, Y J, Q I, J, O, Q, Y I, J, L, O, Q J, O I, K, N, O, Q	M, O, Q, S, U J, O, Q J, M, O, Q, S J, Q, W, Y I, J, Q I, J, Q, Y I, J, O, Q, S, Y I, J, L, O, Q I, L, O, Q I, O, Q, W I I, S I, J, O I, J, L I, O, Y I, O, W, Y K, N, O, Q I, K, N, O, Q K, L, N, O
3	I, O, Q	I, Q	J, O J, O, Q, W J, Q I, J, O, Q, Y I, Q
4		I, O	
5		I, J, O, Q	I, O, Q I, O
7			I, J, O, Q

The results of the cluster analysis support the results of the pairwise dependency analysis for all three classes ($HFACSC_H$, $HFACSC_T$, and $HFACSC_C$). The identical patterns of human error combinations are present in both analyses. The agreement in these analyses demonstrates the significance of Adverse Mental State in rotary wing and TACAIR FMs, while the significance of Crew Resource Management is only significant in rotary wing FMs.

Table 13. Percent of FMs Having the Specific Causal Factor Combinations.

	Percentages		
Combinations	Rotary Wing	TACAIR	Combined Rotary Wing and TACAIR
Q & O	63%	38%	51%
Q & J	51%	37%	45%
Q & I	43%	36%	41%
O & J	40%	41%	44%
O & I	39%	52%	51%
I & J	31%	31%	34%
Q & S	28%	-	-
Q & K	25%	-	-
O & L	24%	-	-
O & S	24%	20%	23%
O & K	22%	22%	24%
Q & L	22%	-	-
Q & M	22%	-	-
O & Y	22%	24%	25%
Q & Y	21%	-	-
O & W	-	22%	21%

C. ANALYSIS OF ACCIDENT ARRIVAL RATES

Gaver (1996) states that models for the occurrence of point event arrivals are relatively simple mathematical formulas, which are specified by one or two parameters from historical data. The homogeneous Poisson model is an example of such a mathematical model that fits a single parameter, λ, to a data set. The parameter λ is estimated for the rotary wing, TACAIR and combined rotary wing and TACAIR FY 90 to FY 97 FMs data sets, where λ is the accident arrival rate/100,000 flight hours. For the rotary wing FY 90 to FY 97 FMs, λ_H is estimated to be 2.4 FMs/100,000 flight hours. For the TACAIR FY 90 to FY 97 FMs, λ_T is estimated to be 3.21 FMs/100,000 flight hours. Finally, for the combined rotary wing and TACAIR FY 90 to FY 97 FMs, λ_C is estimated

to be 2.87 FMs/100,000 flight hours. The data used to estimate λ_H, λ_T and λ_C are displayed in Table 14.

Table 14. Flight Hours and Number of Human Factors Class A and B Rotary Wing, TACAIR and Combined Rotary Wing and TACAIR FMs FY 90 to FY 98.

Fiscal Year	Flight Hours			Number of Class A and B Human Factors FMs		
	Rotary Wing	TACAIR	Combined Rotary Wing and TACAIR	Rotary Wing	TACAIR	Combined Rotary Wing and TACAIR
90	454,750	633,228	1,087,978	8	25	33
91	475,502	660,314	1,135,816	20	23	43
92	421,000	597,393	1,018,393	5	15	20
93	406,329	577,133	983,462	13	23	36
94	377,229	522,700	899,929	11	9	20
95	385,224	503,559	888,783	9	16	25
96	363,583	479,577	843,160	3	18	21
97	320,954	421,150	742,104	8	12	20
98	345,619	406,777	752,396	8	12	20

A χ^2 – goodness of fit test is performed for each model to test the null hypothesis that a Poisson distribution generates the data. Each data set is partitioned in to eight classes, which correspond to FY 90 through FY 97, and the chi-squared test statistic χ^2 is computed as:

$$\chi^2 = \sum_{i=1}^{8} \frac{(O_i - E_i)^2}{E_i}, \tag{19}$$

where O_i and E_i are the observed and estimated expected frequencies in class i for each respective data set. For the rotary wing data set, the resulting test statistic is 15.08, which corresponds to a p-value of .02 with 6 degrees of freedom. For the TACAIR data set, the resulting test statistic is 7.44, which corresponds to a p-value of .28 with 6 degrees of freedom. Finally for the combined rotary wing and TACAIR data set, the resulting test statistic is 10.31, which corresponds to a p-value of .11 with 6 degrees of freedom. Therefore, the null hypothesis that the distributions of rotary wing FMs, TACAIR FMs and combined rotary wing and TACAIR FMs is Poisson can not be rejected at the $\alpha = .01$ significance level.

Gaver (1996) stated:

> Models are not supposed to be perfect representations of the data sets to which they are fitted, but to represent the situation of concern well enough to be useful.

To validate the suitability of the models generated, the accident arrival rates λ_H, λ_T and λ_C and their respective flight hours for FY 98 are used to compute the distribution of rotary wing, TACAIR and combined rotary wing and TACAIR Class A and B FMs for FY 98. From the models, the number of FMs for FY 98 predicted is 8.31 FMs for rotary wing, 13.05 FMs for TACAIR and 21.58 FMs for combined rotary wing and TACAIR. The corresponding actual number of Class A and B FMs for FY 98 are 8 rotary wing FMs, 12 TACAIR FMs and 20 combined rotary wing and TACAIR FMs. Thus, each respective model based on the Poisson distribution is determined to be useful.

D. SIMULATION

The simulation code (see Appendix C), which is a modified version of Jensen's (1999) simulation code, is built using S-Plus© with two principle assumptions:

1) The accident arrivals can be modeled using a Poisson Process.
2) All human error types for future rotary wing, TACAIR and combined rotary wing and TACAIR FMs can be modeled from the 67 rotary wing, 121 TACAIR and 174 combined rotary wing and TACAIR accident combinations found using the MONA function.

The simulation is done for each of the data sets—rotary wing, TACAIR and combined rotary wing and TACAIR. To run a simulation, the average accident arrival rates that are calculated in the previous section for rotary wing, TACAIR and combined rotary wing and TACAIR FY 90 to FY 97 FMs are used to generate accidents from a Poisson distribution, where λ_H is estimated to be 2.4 FMs/100,000 flight hours, λ_T is estimated to be 3.21 FMs/100,000 flight hours and λ_C is estimated to be 2.87 FMs/100,000 flight hours. Each iteration generates an observation from the Poisson distribution, which is specified to be the number of accidents for that particular iteration. A single simulation consists of 1000 iterations, where each iteration represents a time period that consists of a specific number of FMs.

The FMs' characteristics are based on the historical human error causal factors found in FY 90 to FY 97 FMs, which are represented by the $HFACSC_H$, $HFACSC_T$ and $HFACSC_C$ matrices. The characteristics of individual FMs for each period of the

simulation are determined by a uniform random selection, with replacement, between one and the total number of Class A and B FMs from FY 90 to FY 97 for each respective data set, where rotary wing equals 77, TACAIR equals 141 and combined rotary wing and TACAIR equals 218. This is equivalent to a nonparametric sampling bootstrap with replacement from the empirical distribution of historical FM characteristics, which allows for formal inference (Davison & Hinkley, 1997).

To validate the simulation models that are based on the estimated accident arrival rates λ_H, λ_T and λ_C; the rotary wing, TACAIR and the combined rotary wing and TACAIR FY 98 flight hours (see Table 14) are used. To compute the distribution of rotary wing, TACAIR and combined rotary wing and TACAIR FMs predicted for FY 98, the accident arrival rates, λ_H, λ_T and λ_C, and the FY 98 rotary wing, TACAIR and combined rotary wing and TACAIR flight hours are run through 1000 iterations in their respective simulation model. The distributions and 95% Confidence Intervals (CIs) of FY 98 predicted FMs for the three respective simulation models are shown in Figure 2 (rotary wing), Figure 3 (TACAIR) and Figure 4 (combined rotary wing & TACAIR).

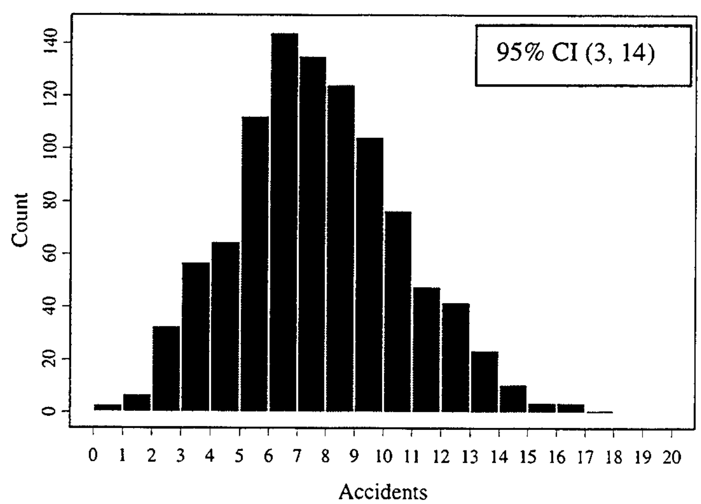

Figure 2. Histogram of 1000 Iterations of the Simulation, Showing the Distribution and 95% CI of Predicted Rotary Wing FMs for FY 98.

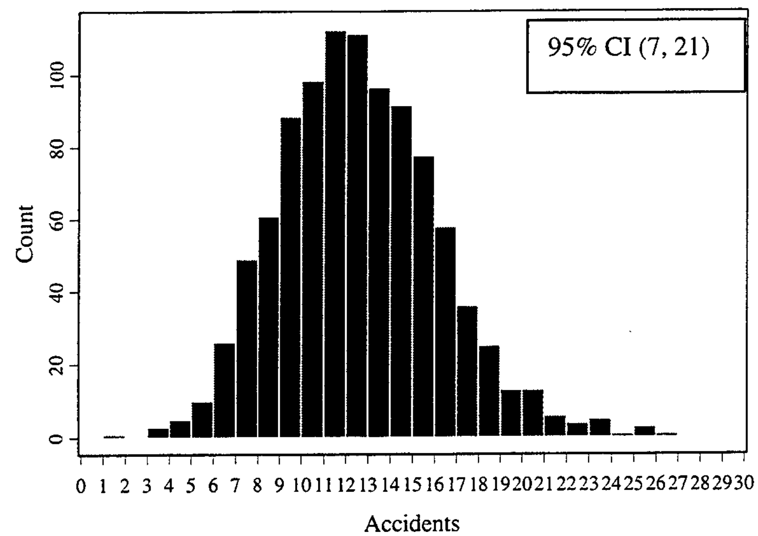

Figure 3. Histogram of 1000 Iterations of the Simulation, Showing the Distribution and 95% CI of Predicted TACAIR FMs for FY 98.

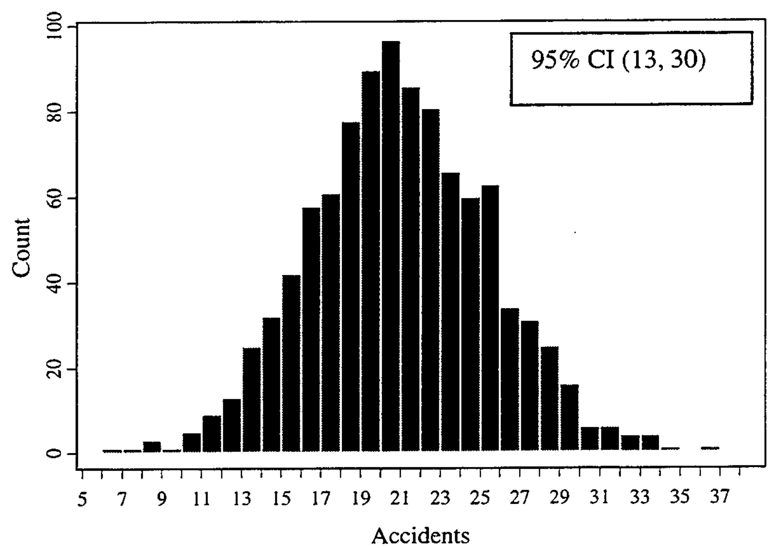

Figure 4. Histogram of 1000 Iterations of the Simulation, Showing the Distribution and 95% CI of Predicted Combined Rotary Wing and TACAIR FMs for FY 98.

Using 345,619 rotary wing flight hours flown for FY 98, the simulation model result is an expected value of 8.245 rotary wing FMs in FY 98, the actual number of rotary wing FMs in FY98 is 8 FMs, which is well within the calculated 95% CI (see Figure 2). Using 406,777 TACAIR flight hours flown for FY 98, the simulation model result is an expected value of 13.12 TACAIR FMs in FY 98, the actual number of TACAIR FMs in FY98 is 12 FMs, which is well within the calculated 95% CI (see Figure 3). Using 752,396 total rotary wing and TACAIR flight hours flown for FY 98, the simulation model result is an expected value of 21.48 combined rotary wing and TACAIR FMs in FY 98, the actual number of combined rotary wing and TACAIR FMs in FY98 is 20 FMs, which is well within the calculated 95% CI (see Figure 4).

To predict the human error types present in future rotary wing, TACAIR and combined rotary wing and TACAIR FMs, the frequency of the human error types for both singularly and the significant combinations of human error types, which were determined in earlier analysis (see Tables 11, 12 & 13), is calculated for the simulation run. For the simulation run of 1000 iterations, the mean and 95 percent CIs for the human error types, singularly and in combination, is calculated and listed in Table D1 in Appendix D. For a human error type, either individually or in combination, to be considered significant, it is hypothesized that at $\alpha = .05$ the expected number of FMs to cite the causal factor is greater than 0, which means the 95% CI does not contain 0.

To validate the 95% CI (see Table D1 in Appendix D) created by the simulation models, the matrices that define the number of rotary wing, TACAIR, and combined rotary wing and TACAIR FY 98 FMs that cite a specific human error type and combinations of human error types are created (see Tables 15, 16 & 17), where,

$$M_{HC98} = (X_{HC98})^T (X_{HC98}), \tag{20}$$

$$M_{TC98} = (X_{TC98})^T (X_{TC98}), \tag{21}$$

$$M_{CC98} = (X_{CC98})^T (X_{CC98}). \tag{22}$$

Of the 35, 95% CIs (see Table D1 in Appendix D) found to be significant at $\alpha = .05$ level, only one set of FY 98 FMs causal factors does not fit in the computed 95% CIs. This set is located in the combined rotary wing and TACAIR data set, M_{cc98} cell (l, l) (see Table 17), which equals zero and the calculated 95% CI is (1, 9). This result is expected

since at an $\alpha = .05$ significance level, it is expected to reject the null hypothesis in error 1 out of 20 times. Thus, the computed CIs are satisfactory to conduct analysis.

Table 15. Matrix M_{HC98}, Depicting the Number of Rotary Wing FY 98 FMs that Contain an Individual Set or Intersecting Sets of Causal Factors.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	6	2	2	0	0	2	5	0	4	0	2	0	1	0	0	0	2
J		4	2	0	0	1	3	1	4	0	0	0	0	0	0	0	1
K			3	0	0	2	3	0	3	0	0	0	0	0	0	0	1
L				0	0	0	0	0	0	0	0	0	0	0	0	0	0
M					0	0	0	0	0	0	0	0	0	0	0	0	0
N						2	2	0	2	0	0	0	0	0	0	0	1
O							6	0	5	0	1	0	1	0	0	0	1
P								1	1	0	0	0	0	0	0	0	0
Q									6	0	1	0	1	0	0	0	1
R										0	0	0	0	0	0	0	0
S											2	0	1	0	0	0	1
T												0	0	0	0	0	0
U													1	0	0	0	0
V														0	0	0	0
W															0	0	0
X																0	0
Y																	2

Table 16. Matrix M_{TC98}, Depicting the Number of TACAIR FY 98 FMs that Contain an individual Set or Intersecting Sets of Causal Factors.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	3	1	0	0	0	0	3	0	2	0	1	0	0	0	0	0	1
J		5	1	0	0	0	2	0	4	0	1	0	0	0	2	0	2
K			1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
L				0	0	0	0	0	0	0	0	0	0	0	0	0	0
M					0	0	0	0	0	0	0	0	0	0	0	0	0
N						0	0	0	0	0	0	0	0	0	0	0	0
O							4	0	2	0	1	0	0	0	1	0	1
P								0	0	0	0	0	0	0	0	0	0
Q									5	0	1	0	0	0	1	0	2
R										0	0	0	0	0	0	0	0
S											1	0	0	0	0	0	1
T												0	0	0	0	0	0
U													0	0	0	0	0
V														0	0	0	0
W															2	0	0
X																0	0
Y																	2

Table 17. Matrix M_{CC98}, Depicting the Number of Combined Rotary Wing and TACAIR FY 98 FMs that Contain an Individual Set or Intersecting Sets of Causal Factors.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	9	3	2	0	0	2	8	0	6	0	3	0	1	0	0	0	3
J		9	3	0	0	1	5	1	8	0	1	0	0	0	2	0	3
K			4	0	0	2	3	0	4	0	0	0	0	0	0	0	1
L				0	0	0	0	0	0	0	0	0	0	0	0	0	0
M					0	0	0	0	0	0	0	0	0	0	0	0	0
N						2	2	0	2	0	0	0	0	0	0	0	1
O							10	0	7	0	2	0	1	0	1	0	2
P								1	1	0	0	0	0	0	0	0	0
Q									11	0	2	0	1	0	1	0	3
R										0	0	0	0	0	0	0	0
S											3	0	1	0	0	0	2
T												0	0	0	0	0	0
U													1	0	0	0	0
V														0	0	0	0
W															2	0	0
X																0	0
Y																	4

For rotary wing, the singular human error types found to be significant at $\alpha = .05$ are I (Skill-Based Error), J (Decision Error), O (Adverse Mental State) and Q (Crew Resource Management). When examining the combination of human error types, the only combination found to be significant at $\alpha = .05$ is Q (Crew Resource Management) — O (Adverse Mental State). For TACAIR, the singular human error types found to be significant at $\alpha = .05$ are I (Skill-Based Error), J (Decision Error), O (Adverse Mental State), Q (Crew Resource Management), W (Organizational Resource Management) and Y (Organizational Process). When examining the combination of human error types, the combinations found to be significant at $\alpha = .05$ are Q (Crew Resource Management) — O (Adverse Mental State), Q (Crew Resource Management) — J (Decision Error), Q (Crew Resource Management) — I (Skill-Based Error), O (Adverse Mental State) — J (Decision Error) and O (Adverse Mental State) — I (Skill-Based Error). For the combined rotary wing and TACAIR, the singular human error types found to be significant at $\alpha = .05$ are all the significant singular human error types for TACAIR, plus K (Perceptual Errors), L (Infraction), N (Adverse Physiological State) and S (Inadequate Supervision). When examining the combination of human error types, the combinations

found to be significant at $\alpha = .05$ are the same combination of human error types for TACAIR, plus I (Skill-Based Error) — J (Decision Error), O (Adverse Mental State) — S (Inadequate Supervision), O (Adverse Mental State) — K (Perceptual Error) and O (Adverse Mental State) — Y (Organizational Process). All significant human error types are determined using Table D1 in Appendix D.

The singular human error types found to be significant in earlier analysis are I (Skill-Based Error), J (Decidion Error), O (Adverse Mental State), Q (Crew Resource Management), S (Inadequate Supervision) and Y (Organizational Process). All of these human error types are found to be significant in the results of the simulation, as well. Also, the simulation determined the following additional singular human error types to be significant—K (Perceptual Error), L (Infraction) and W (Resource Management).

The results of the simulation support the results in the cluster analysis and the pairwise dependency analysis for human error type O (Adverse Mental State). Adverse Mental State is found to be significant throughout NA, where it is present in the one significant combination for the rotary wing data set; present in three of the five significant combinations for the TACAIR data set; and present in six of the nine significant combinations for the combined rotary wing and TACAIR data set. However, the simulation supports the results in the cluster analysis and the pairwise dependency analysis for human error type Q (Crew Resource Management—CRM) to a lesser degree. CRM is present in the one significant combination for the rotary wing data set. In addition, CRM is found to be significant in three of the five significant combinations for the TACAIR data set and three of the nine significant combinations for the combined rotary wing and TACAIR data set.

E. ANALYSIS OF CAUSAL FACTOR RATES/100,000 FLIGHT HOURS

Results of previous analysis in this study shows that the four dominant single causal factors are: I (Skill-Based Error), J (Decision Error), O (Adverse Mental State) and Q (Crew Resource Management). Figure 5 visually shows the rotary wing, TACAIR, and combined rotary wing and TACAIR average causal factor Rates/100,000 flight hours from FY 90 to FY 97, which iterates this fact. Tables E1, E2 and E3 (see Appendix E) list, by FY, the individual causal factor rates/100,000 flight hours for FY 90 to FY 98. In addition, Tables E4, E5 and E6 (see Appendix E) contain the average causal factor

rates/100,000 flight hours for single causal factors and combinations of causal factors for FY 90 to FY 97. For example, cell (I, I) for Table E4 represents the mean accident rates/100,000 flight hours caused by causal factor Skill-Based Error, while cell (O, I) represents the mean accidents/100,000 flight hours caused by the causal factor combination of Adverse Mental State and Skill-Based Error. Table 18 summarizes the mean accident rates/100,000 flight hours from FY 90 to FY 97 for the dominant single causal factors and the combination of causal factors. For a single causal factor to be considered dominant, the mean accident rate/100,000 flight hours for the causal factor is greater than 1.0 and for a combination of causal factors to be considered dominant, the mean accident rate/100,000 flight hours for the combination is greater than 0.8 (see Tables E4, E5 & E6 in Appendix E). These dominant causal factors and causal factor combinations are used to assess the effectiveness of proposed intervention strategies.

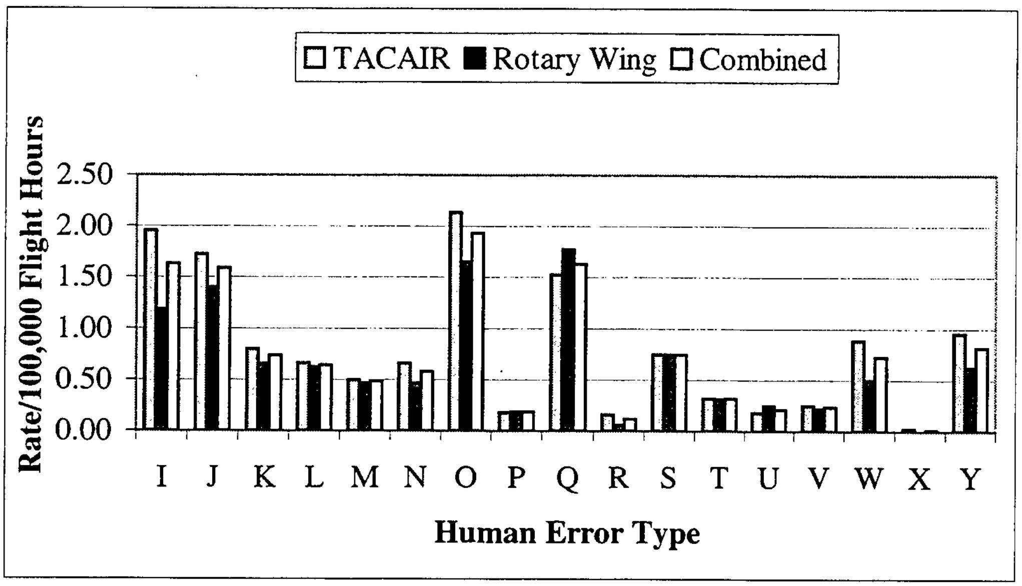

Figure 5. Rotary Wing, TACAIR, and Combined Rotary Wing and TACAIR Average Causal Factor Rates/100,000 Flight Hours from FY 90 to FY 97.

Table 18. Mean Accident Rates/100,000 Flight Hours for the Significant Causal Factors (Singular & Combinations) for FY 90 to FY 97.

Causal Factors (Single/Combination)	Rotary Wing	TACAIR	Combined Rotary Wing and TACAIR
I	1.19	1.96	1.63
J	1.40	1.73	1.59
O	1.65	2.14	1.93
Q	1.78	1.52	1.63
O & Q	1.31	1.05	1.16
O & I	.81	1.43	1.17
O & J	.84	1.14	1.01
Q & I	.90	.98	.95
Q & J	1.06	1.02	1.04
I & J	.66	.86	.78

When exploring possible intervention strategies, it is not enough just to look at programs that consist of classroom or seminar type training. This fact is evident in the intervention strategy for Crew Resource Management developed for all of NA to reduce the number of FMs caused by Crew Resource Management. By FY 94, the Navy established a program, known as "Aircrew Coordination Training" (ACT), to increase the awareness of Crew Resource Management (Jensen, 1999). This program is implemented into the training and safety programs for all aviation squadrons throughout NA. Examining the rotary wing, TACAIR and combined rotary wing and TACAIR FMs data, it is evident that the arrival rates for Crew Resource Management do not demonstrate a significant decline in the mean arrival rates for Crew Resource Management between FY 94 and FY 97 (see Figure 6 & Tables E1, E2 & E3 in Appendix E). This fact does not suggest that the ACT program has not made an impact in NA. Instead, it reveals that ACT is a first step in reducing FMs caused by Crew Resource Management through awareness and techniques training. However, a means to practice the techniques and to evaluate the effectiveness of crew coordination needs to be developed.

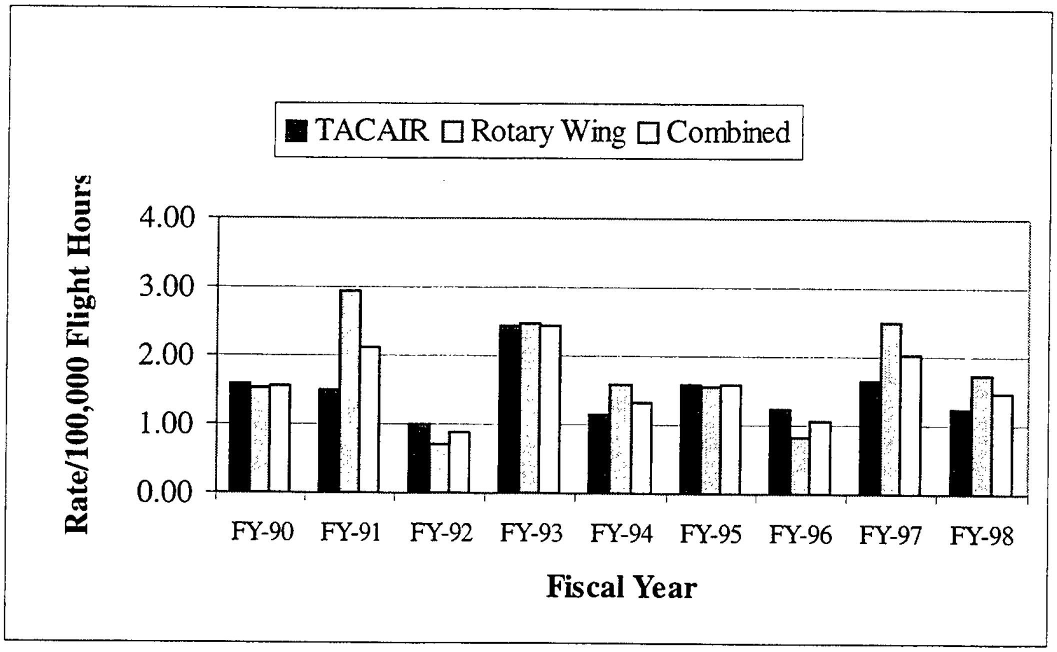

Figure 6. Crew Resource Management (CRM) Arrival Rate/100,000 Flight Hours for FY 90 to FY 98.

Due to the non-mutually exclusiveness of the causal factors I...Y, to compare rotary wing and TACAIR causal factor arrival rates/100,000 flight hours a nonparametric procedure is necessary to perform statistical inference. The sign test, a robust and conservative statistical test, is used, because it makes no assumptions of the underlying distribution and is a nonparametric procedure (Devore, 1995). To perform the sign test, the average arrival rate for each causal factor is calculated by using the total number of times a causal factor is cited (see Tables 2, 3 & 4) and the total flight hours (see Table 14) for the rotary wing, TACAIR and combined rotary wing and TACAIR FMs between FY 90 and FY 97. The average arrival rates for the 17 single causal factor arrival rates/100,000 flight hours are located on the diagonals of Tables E4 and E5 (see Appendix E).

Assuming that the average arrival rates for the causal factors occur at even rates between the rotary wing and the TACAIR communities, there would be a fifty percent chance in any given category that one is higher than the other. It is expected that 8.5 of the TACAIR causal factor's average arrival rates would be larger than the corresponding rotary wing rates. Figure 5 graphically shows that the average arrival rates for the causal factors for TACAIR is larger than the respective rotary wing average arrival rates in 14 of

the 17 causal factors. This equates to a p-value of .0127 when testing the null hypothesis that the probability of equal arrival rates equals 50 percent. Thus we fail to reject the null hypothesis at a significance of α = .01 and assume the arrival rates to be equal. When looking at the FY 98 average arrival rates for the causal factors (see Tables E1 & E2 in Appendix E), the TACAIR rates are only larger than the rotary wing arrival rates in 2 of the 17 causal factors, which supports the failure to reject the null hypothesis that the probability of equal rates equals 50 percent.

F. POTENTIAL INTERVENTION COST SAVINGS

The total cost for all rotary wing FY 98 Class A and B FMs is approximately $84 million and the total cost for all TACAIR FY 98 Class A and B FMs is approximately $563 million, which equates to an average cost of $8 million and $22 million, respectively (Pruhs, 2000). The total cost for the combined rotary wing and TACAIR FY 98 Class A and B FMs is approximately $647.5 million, with an average cost of $17.5 million. It is evident that the most effective way to minimize these associated costs is to target intervention strategies at the most prevalent forms of human error, which are Adverse Mental State, Crew Resource Management, Skill-Based Error and Decision Error. This study will use the mean causal factor rate/100,000 flight hours reduced by the goals that the Human Factors Quality Management Board (HFQMB) set for reducing FMs caused by human error, which were 50 percent within 3 years and 75 percent within 10 years, to evaluate the impact of proposed intervention strategies.

The data used to evaluate the proposed reduction of 50 percent and 75 percent of the causal factor mean arrival rates/100,000 flight hours will be the mean arrival rates/100,000 flight hours for FY 90 to FY 97 (see Table 18), the number of flight hours for FY 98 (see Table 14) and the average cost of FMs for FY 98. Table 19 summarizes the potential cost savings with the proposed reductions of 50 percent and 75 percent in the mean arrival rates/100,000 flight hours for the significant causal factors and causal factors combinations, as seen in Table 18. Looking at rotary wing Skill-Based Error, as an example, a strategy that is 50 percent successful in intervention would equate to an expected reduction in rotary wing FMs of .60 FMs/100,000 flight hours (see Table 18). Using the rotary wing flight hours for FY 98 (see Table 14), the expected reduction in

FMs would be 2.056 FMs. Using the average cost of rotary wing FMs for FY 98, the resulting savings would be approximately $16.5 million for FY 98 (see Table 19).

Table 19. Potential Cost Savings with 50% and 75% Reduction in Mean Accident Rates/100,000 Flight Hours for the Significant Causal Factors (Singular & Combinations)—Units in Millions of Dollars.

Causal Factors (Single/Combination)	50% Reduction in Mean/100,000 Flight Hours			75% Reduction in Mean/100,000 Flight Hours		
	Rotary Wing	TACAIR	Combined Rotary Wing and TACAIR	Rotary Wing	TACAIR	Combined Rotary Wing and TACAIR
I	$16.5	$87.7	$107.3	$24.7	$131.6	$161.0
J	$19.4	$77.4	$104.7	$29.0	$116.1	$157.0
O	$22.8	$95.8	$127.1	$34.2	$143.6	$190.6
Q	$24.6	$68.0	$107.3	$36.9	$102.0	$161.0
O & Q	$18.1	$47.0	$76.4	$27.2	$70.5	$114.6
O & I	$11.2	$64.0	$77.0	$16.8	$96.0	$115.5
O & J	$11.6	$51.0	$66.5	$17.4	$76.5	$99.7
Q & I	$12.4	$43.9	$62.5	$18.7	$65.8	$93.8
Q & J	$14.7	$45.6	$68.5	$22.0	$68.5	$102.7
I & J	$9.1	$38.5	$51.4	$13.7	$57.7	$77.0

Due to the fact that more than one causal factor or causal factor combination can be cited in a FM report, it is not feasible to get a total dollar value for the potential cost savings for reductions in arrival rates. Thus, the impact of the 50 percent and 75 percent reduction in causal factor mean arrival rates can only be given a range of dollar values. As an example, Table 19 shows that the associate cost savings for a 50 percent reduction in mean causal factor arrival rates/100,000 flight hours for rotary wing FMs ranges from $9.1 million (for I & J combination) to $24.6 million (for Q). For rotary wing, intervention at the causal factor Q provides the largest potential cost savings for 50 percent and 75 percent reductions, while TACAIR largest potential cost savings is found in strategies aimed at the causal factor O (see Table 19).

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V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

Aviation is an inherently dangerous operation, which is subject to a large number of risks and influential factors. Human error has been implicated as the largest single factor in Naval Aviation (NA) flight mishaps (FMs). The average cost of all NA Class A and B FMs (all types and models of aircraft) for FY 98 is $17 million per FM, which results in a substantial total of approximately $775 million (Pruhs, 2000). In the midst of reduced budgets and limited resources, the NA FMs caused primarily by human error must be analyzed to determine the most effective intervention strategies to reduce human-error-related FMs and their associated costs. To address the need to identify the human error patterns in NA, post-hoc analysis of the 77 rotary wing and 141 Tactical Aircraft (TACAIR) Class A and B human error FMs from 1 October 1989 to 30 September 1998 is conducted using the Human Factors Analysis and Classification System (HFACS) taxonomy.

The HFACS is a taxonomy, which applies the theory of human error to the accident investigation and analysis process to answer the question of "Why did the FM happen?" The HFACS taxonomy takes approximately 289 human error types and classifies them into 25 distinct human error groups. The HFACS taxonomy has a hierarchical relationship, which permits focused analysis on the 17 basic human error types related to NA. However, when analyzing the NA FMs that are principally due to human error, several human error types are normally cited as causal factors for each FM. These cited causal factors are not ranked in any order of importance. These facts make traditional statistical analysis techniques impractical, due to the non-mutually exclusive nature of the associated human error types in the HFACS taxonomy. The analysis for this study includes data exploration, cluster analysis, a nonparametric simulation model to predict future human error patterns, analysis of causal factors arrival rates and an assessment of the potential cost savings of intervention strategies.

Skill-Based Error (SBE), Decision Error (DE), Adverse Mental State (AMS) and Crew Resource Management (CRM) are the dominant significant human error causal factors found in this study of human error in rotary wing and TACAIR FMs between FY 90 and FY 97. In the exploratory analysis, all four of these causal factors are found to

occur the largest proportion of the time. When examining the combination of human error causal factors, AMS is found to have an important relationship with 9 of the 17 basic human error types for rotary wing and TACAIR FMs, while AMS has an important relationship with 11 of the 17 basic human error types for the combined rotary wing and TACAIR FMs. CRM is found to only have an important relationship in rotary wing FMs, which affect 12 of the 17 basic human error types.

To predict future number of FMs and their related patterns of human error, a nonparametric simulation technique, called the bootstrap method, is used. In order to use the nonparametric bootstrap method, two assumptions are made. First, the accident arrival rates can be modeled using a Poisson Process, which is verified using the "Chi-squared" goodness of fit test. Next, the FMs human error characteristics can be modeled using the combinations of the historical human error characteristics of the mishap data. Using a monothetic divisive algorithm for cluster analysis, the rotary wing FMs cluster into 67 separate combinations, the TACAIR FMs cluster into 121 separate combinations and the combined rotary wing and TACAIR FMs cluster into 174 separate combinations. These combinations are used to represent the human error characteristics for the simulation models. The simulation calculates the mean and the 95 percent Confidence Intervals (CIs) for the basic human error types for each model, which are rotary wing, TACAIR and combined rotary wing and TACAIR models.

For all three of the simulation models, the single causal factors SBE, DE, AMS and CRM are found to be significant throughout NA. The only significant combination found throughout NA is AMS—CRM, which is the only significant combination for the rotary wing model. Whereas, the causal factors AMS and CRM are found to be in 3 of the 5 significant combinations and SBE and DE are found to be in 2 of the 5 significant combinations for the TACAIR model. Finally, the causal factors AMS and CRM are found to be in 3 of the 6 significant combinations and SBE and DE are found to be in 3 of the 6 significant combinations for the combined rotary wing and TACAIR model. The analysis of the causal factor arrival rates/100,000 flight hours supports the results of the simulation by showing that the dominant causal factors are SBE, DE, AMS and CRM for rotary wing, TACAIR and the combined rotary wing and TACAIR FMs.

Initially, CRM is only found to be prevalent in rotary wing FMs. However, the simulation and analysis of causal factors arrival rates has demonstrated its impact throughout NA. To illustrate this result, TACAIR is generally considered single-piloted, but the human error type CRM accounts for personnel that are outside of the cockpit or system as well. Therefore, the intervention strategies to be implemented should be aimed at SBE, DE, AMS and CRM, singularly and in combination with one another, for the entire NA. The potential cost savings of reducing these causal factor mean arrival rates/100,000 flight hours by 50 percent and 75 percent is calculated to emphasize the impact intervention strategies can have for NA. The largest impact of cost savings is seen by a reduction in CRM for the rotary wing FMs and by a reduction in AMS for the TACAIR FMs.

B. CONCLUSIONS

This study examines human error in NA rotary wing and TACAIR FMs from FY 90 to FY 98 using the HFACS taxonomy. The objectives of this study are to determine if predictive patterns and relationships of human error can be identified in NA FMs, if future NA FM rates and associated causal factors can be forecasted and if intervention strategies can be identified for the primary human factor patterns discovered. The analysis of this study using the HFACS taxonomy permits all three of the objectives to be met.

In this analysis, it is clearly evident that AMS, CRM, SBE and DE are the dominant forms of human error types present in the rotary wing and TACAIR FMs. No other forms of human error patterns stand out as prevalent as these. When comparing the rotary wing and TACAIR results, the major difference is found in the pairwise dependency of causal factors. CRM is found to be significant in 12 of the 17 relationships and AMS is found to be significant in 9 of the 17 relationships between basic human error types for rotary wing. For TACAIR, AMS is found to be significant in 9 of the 17 relationships between basic human error types. When combining the rotary wing and TACAIR FMs the result is that AMS is found to be significant in 11 of the 17 relationships between basic human error types.

Using the nonparametric simulation models developed for the rotary wing, TACAIR and combined rotary wing and TACAIR data sets, it is demonstrated

statistically that future FM rates and their associated causal factors can be forecasted. The modeling of mishap events using a Poisson process is an effective technique, which allows the results of this analysis to focus potential intervention strategies. It is found that when looking at a 50 percent and 75 percent reduction in the mean causal factor arrival rates/100,000 flight hours, the largest potential cost savings are found in intervention strategies that target CRM for rotary wing FMs and AMS for TACAIR FMs.

C. RECOMMENDATIONS

To meet the goals set by the HFQMB in 1996 of reducing FMs caused by human error by 50 percent in three years and 75 percent in 10 years, it will require an aggressive and dedicated effort throughout NA to implement the necessary intervention strategies. This study reveals that human error forms SBE, DE, AMS and CRM are the most prevalent forms of human error in rotary wing and TACAIR FMs between FY 90 and FY 97. Thus, targeting these human error forms for intervention strategies provides the best possible means to achieve the HFQMB goals.

The most effective intervention strategies for the patterns of human error causal factors found in this study are associated with the use of flight simulators throughout NA. Simulators provide an opportunity to conduct training, to include the practice of emergency procedures, which would be dangerous or impossible to conduct in the actual aircraft. Due to the fact that individual flight simulators and aircraft are configured differently and that the missions and flight profiles are not the same for all aircraft communities, the implementation of these interventions will have to be tailored for individual communities and type aircraft. These intervention strategies are targeted at the fleet squadrons. However, where applicable, some of the strategies may carry over to the Fleet Replacement Squadrons (FRS) and flight school.

First, a requirement for an "Emergency Procedures Simulator" (EP Sim) to be flown every 90 days with a Naval Aviation Training and Standard Operating Procedures (NATOPS) Instructor (NI) or Assistant NI (ANI) should be adopted. This policy is primarily targeted at reducing SBE errors and to a lesser degree the DE, AMS, and CRM errors. In addition, the Naval Safety Center (NSC) and the Sytems Engineering Test Directorate (SETD) at Naval Air Station Patuxent River, MD (PAX River) should design training scenarios, which are based on actual flight Mishap Investigation Reports (MIRs),

tailored for each individual aircraft community. This policy is targeted at all four of the human error types (SBE, DE, AMS & CRM).

Typically when an aircrew is scheduled for a tactical flight in the simulator, the aircrew is required to perform various tactical skills to complete the event. Included in the tactical skills is to trouble shoot mission-related malfunctions in systems while conducting the flight. At the conclusion of the tactical portion of the event, the aircrew is typically given an emergency procedure to complete and the event is finished. The aircrew knows when to expect the emergency procedure at the end of the flight. Instead, the emergency procedure should be conducted at various points of the event and could be based on the scenarios recommended by NSC and SETD. This practice would also address all four types of human error targeted for reduction.

An additional process should be added to the ACT program currently employed by the Navy. This process is to videotape aircrews during simulator events and to allow the aircrews to review the tape at the conclusion of the flight. During the review, the instructor or facilitator would critique the flight with the aircrew. This policy is currently employed by major civilian airlines. This policy would strictly be an educational tool and the tapes should only be reviewed by the aircrew and then erased. This policy addresses the human error type CRM. In addition, the equipment used to track a pilot's scan pattern could be used as a training aid to determine where the pilot is focusing attention and to determine if his errors are caused by misguided attentional control. This feature would address the human error type AMS, both singularly and in combination with CRM.

When examining human error in NA FMs not all information is available, the analysis is done on a biased data set. First, not all human errors committed by aircrew result in a FM, which causes nonresponse bias. When a FM does occur due to human error by aircrew and the result of the FM is loss of life, the MIR concerning human error is based on engineering investigations, but they are still judgements of what happened and subject to misinterpretation. However, post hoc analysis is the best technique currently available. It is recommended that NSC and SETD develop a designed experiment to conduct with the use of flight simulators in an effort to determine what are the common errors found for each NA community. The scenarios for the experiment would be based on the MIRs of past FMs for each NA community.

All of these intervention strategies are feasible, because all of the tools and capabilities are available to implement them. To implement, the resources would have to be acquired and installed and the scenarios developed. No estimates for the cost of these proposed intervention strategies have been done for this analysis. A reasonable time estimate to incorporate these proposals is about one year.

Finally, due to the complexity and nature of human error, future studies for the analysis of human error in FMs are needed. One type of analysis is to investigate human errors during the different phases of flight (i.e., takeoff, types of mission, transit, landing, etc...). Another analysis is to determine if the safety climate surveys are effective in predicting human error related FMs.

APPENDIX A. KEY TO HFACS CODING A,...,Y

Table A1. Key to Human Error Types Coding for the HFACS Taxonomy.

Coding	HFACS Causal Factor
A	Unsafe Acts
B	Preconditions for Unsafe Acts
C	Unsafe Supervision
D	Organizational Influence
E	Errors
F	Violations
G	Substandard Conditions of Operators
H	Substandard Practices of Operators
I	Skill-Based Errors
J	Decision Errors
K	Perceptual Errors
L	Infraction
M	Exceptional
N	Adverse Physiological State
O	Adverse Mental State
P	Physical/Mental Limitation
Q	Crew Resource Management (CRM)
R	Personal Readiness
S	Inadequate Supervision
T	Planned Inappropriate Operations
U	Failed to Correct Problem
V	Supervisory Violation
W	Resource Management
X	Organizational Climate
Y	Organizational Process

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APPENDIX B. CORRELATION MATRICES FOR MATRICES $HFACSA_H$, $HFACSB_H$, $HFACSC_H$, $HFACSA_T$, $HFACSB_T$ AND $HFACSC_T$

Table B1. Correlation Matrix for $HFACSA_H$ (X_{HA}).

	A	B	C	D
A	1.000	0.480	-0.174	-0.210
B	0.480	1.000	-0.107	0.001
C	-0.174	-0.107	1.000	-0.030
D	-0.210	0.001	-0.030	1.000

Table B2. Correlation Matrix for $HFACSB_H$ (X_{HB}).

	E	F	G	H	C	D
E	1.000	-0.278	0.073	-0.031	-0.307	-0.051
F	-0.278	1.000	0.224	0.184	0.398	-0.146
G	0.073	0.224	1.000	0.211	-0.007	0.134
H	-0.031	0.184	0.211	1.000	0.080	-0.151
C	-0.307	0.398	-0.007	0.080	1.000	-0.030
D	-0.051	-0.146	0.134	-0.151	-0.030	1.000

Table B3. Correlation Matrix for $HFACSC_H$ (X_{HC}).

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	1.000	-0.064	-0.196	0.067	-0.158	-0.158	-0.009	0.004	0.052	-0.161	0.009	0.005	-0.166	-0.041	-0.057		0.067
J	-0.064	1.000	0.102	-0.041	-0.251	0.016	-0.226	0.147	0.041	-0.028	-0.001	-0.066	-0.404	-0.008	0.042		0.019
K	-0.196	0.102	1.000	0.036	0.067	0.730	0.034	0.040	0.097	-0.100	-0.034	0.110	-0.113	0.111	0.118		-0.030
L	0.067	-0.041	0.036	1.000	0.008	0.157	0.143	0.159	0.013	0.089	0.433	0.124	0.187	0.019	-0.157		0.054
M	-0.158	-0.251	0.067	0.008	1.000	0.006	0.189	-0.143	0.291	0.126	0.165	0.005	0.370	0.301	-0.009		0.083
N	-0.158	0.016	0.730	0.157	0.006	1.000	0.189	-0.021	0.067	-0.080	-0.048	0.103	0.047	-0.041	0.233		0.083
O	-0.009	-0.226	0.034	0.143	0.189	0.189	1.000	-0.118	0.177	-0.066	-0.031	0.177	0.137	0.115	-0.070		0.079
P	0.004	0.147	0.040	0.159	-0.143	-0.021	-0.118	1.000	-0.049	-0.047	0.223	-0.112	-0.099	0.077	-0.029		0.049
Q	0.052	0.041	0.097	0.013	0.291	0.067	0.177	-0.049	1.000	0.097	0.079	0.141	0.105	0.084	-0.135		-0.054
R	-0.161	-0.028	-0.100	0.089	0.126	-0.080	-0.066	-0.047	0.097	1.000	-0.110	0.180	0.212	0.232	-0.084		0.089
S	0.009	-0.001	-0.034	0.433	0.165	-0.048	-0.031	0.223	0.079	-0.110	1.000	0.074	0.230	-0.018	-0.206		-0.079
T	0.005	-0.066	0.110	0.124	0.005	0.103	0.177	-0.112	0.141	0.180	0.074	1.000	0.122	0.147	-0.007		0.035
U	-0.166	-0.404	-0.113	0.187	0.370	0.047	0.137	-0.099	0.105	0.212	0.230	0.122	1.000	0.040	-0.174		0.090
V	-0.041	-0.008	0.111	0.019	0.301	-0.041	0.115	0.077	0.084	0.232	-0.018	0.147	0.040	1.000	0.061		0.225
W	-0.057	0.042	0.118	-0.157	-0.009	0.233	-0.070	-0.029	-0.135	-0.084	-0.206	-0.007	-0.174	0.061	1.000		0.208
X																	
Y	0.067	0.019	-0.030	0.054	0.083	0.083	0.079	0.049	-0.054	0.089	-0.079	0.035	0.090	0.225	0.208		1.000

Table B4. Correlation Matrix for $HFACSA_T$ (X_{TA}).

	A	B	C	D
A	1.000	-0.034	-0.118	0.079
B	-0.034	1.000	0.120	-0.067
C	-0.118	0.120	1.000	0.016
D	0.079	-0.067	0.016	1.000

Table B5. Correlation Matrix for $HFACSB_T$ (X_{TB}).

	E	F	G	H	C	D
E	1.000	-0.228	0.179	0.075	0.077	-0.084
F	-0.228	1.000	-0.166	-0.045	-0.021	-0.168
G	0.179	-0.166	1.000	0.013	0.120	-0.009
H	0.075	-0.045	0.013	1.000	0.045	-0.048
C	0.077	-0.021	0.120	0.045	1.000	0.016
D	-0.084	-0.168	-0.009	-0.048	0.016	1.000

Table B6. Correlation Matrix for $HFACSC_T$ (X_{TC}).

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	1.000	-0.244	-0.214	-0.133	-0.297	-0.025	0.175	0.070	0.062	-0.018	-0.039	-0.026	0.070	0.124	-0.026	0.068	-0.020
J	-0.244	1.000	-0.193	0.013	0.045	-0.128	-0.020	-0.204	0.253	-0.051	0.041	0.117	0.104	0.110	-0.001	-0.091	0.105
K	-0.214	-0.193	1.000	0.195	0.115	0.601	0.128	0.001	-0.119	0.171	0.031	-0.026	0.072	-0.045	-0.025	0.147	-0.087
L	-0.133	0.013	0.195	1.000	0.023	0.132	-0.087	-0.049	-0.063	0.045	0.009	-0.110	0.179	0.048	-0.119	0.166	-0.063
M	-0.297	0.045	0.115	0.023	1.000	0.023	-0.193	0.064	-0.018	0.082	-0.099	-0.012	-0.021	-0.052	-0.091	0.197	-0.195
N	-0.025	-0.128	0.601	0.132	0.023	1.000	0.136	0.027	-0.133	0.126	0.009	-0.052	0.103	-0.017	0.038	0.166	0.014
O	0.175	-0.020	0.128	-0.087	-0.193	0.136	1.000	0.108	0.040	0.092	0.071	0.184	0.173	0.093	0.034	0.060	0.033
P	0.070	-0.204	0.001	-0.049	0.064	0.027	0.108	1.000	0.074	0.085	-0.063	-0.081	0.072	0.043	0.054	-0.021	-0.026
Q	0.062	0.253	-0.119	-0.063	-0.018	-0.133	0.040	0.074	1.000	-0.087	-0.023	-0.031	0.012	-0.012	-0.144	0.089	-0.030
R	-0.018	-0.051	0.171	0.045	0.082	0.126	0.092	0.085	-0.087	1.000	0.182	0.033	0.085	0.055	-0.141	-0.019	-0.006
S	-0.039	0.041	0.031	0.009	-0.099	0.009	0.071	-0.063	-0.023	0.182	1.000	0.209	0.082	0.151	-0.042	-0.047	0.043
T	-0.026	0.117	-0.026	-0.110	-0.012	-0.052	0.184	-0.081	-0.031	0.033	0.209	1.000	-0.081	-0.008	0.007	-0.028	0.043
U	0.070	0.104	0.072	0.179	-0.021	0.103	0.173	0.072	0.012	0.085	0.082	-0.081	1.000	0.386	0.054	0.345	-0.026
V	0.124	0.110	-0.045	0.048	-0.052	-0.017	0.093	0.043	-0.012	0.055	0.151	-0.008	0.386	1.000	0.116	-0.025	-0.016
W	-0.026	-0.001	-0.025	-0.119	-0.091	0.038	0.034	0.054	-0.144	-0.141	-0.042	0.007	0.054	0.116	1.000	-0.052	0.152
X	0.068	-0.091	0.147	0.166	0.197	0.166	0.060	-0.021	0.089	-0.019	-0.047	-0.028	0.345	-0.025	-0.052	1.000	-0.055
Y	-0.020	0.105	-0.087	-0.063	-0.195	0.014	0.033	-0.026	-0.030	-0.006	0.043	0.043	-0.026	-0.016	0.152	-0.055	1.000

Table B7. Correlation Matrix for $HFACSA_C$ (X_{CA}).

	A	B	C	D
A	1.000	0.190	-0.149	-0.055
B	0.190	1.000	0.050	-0.050
C	-0.149	0.050	1.000	-0.012
D	-0.055	-0.050	-0.012	1.000

Table B8. Correlation Matrix for $HFACSB_C$ (X_{CB}).

	E	F	G	H	C	D
E	1.000	-0.254	0.120	-0.005	-0.120	-0.053
F	-0.254	1.000	-0.025	0.048	0.145	-0.166
G	0.120	-0.025	1.000	0.082	0.079	0.036
H	-0.005	0.048	0.082	1.000	0.082	-0.098
C	-0.120	0.145	0.079	0.082	1.000	-0.012
D	-0.053	-0.166	0.036	-0.098	-0.012	1.000

Table B9. Correlation Matrix for $HFACSC_C$ (X_{CC}).

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	1.000	-0.183	-0.209	-0.064	-0.248	-0.070	0.106	0.039	0.027	-0.052	-0.030	-0.019	-0.039	0.059	-0.027	0.059	0.015
J	-0.183	1.000	-0.086	-0.004	-0.062	-0.079	-0.090	-0.067	0.190	-0.046	0.029	0.050	-0.102	0.067	0.010	-0.076	0.073
K	-0.209	-0.086	1.000	0.136	0.098	0.646	0.095	0.017	-0.039	0.089	0.009	0.028	-0.004	0.014	0.021	0.115	-0.068
L	-0.064	-0.004	0.136	1.000	0.020	0.140	-0.001	0.038	-0.019	0.054	0.180	-0.014	0.186	0.038	-0.136	0.126	-0.023
M	-0.248	-0.062	0.098	0.020	1.000	0.016	-0.051	-0.019	0.098	0.090	0.009	-0.003	0.154	0.086	-0.066	0.150	-0.095
N	-0.070	-0.079	0.646	0.140	0.016	1.000	0.154	0.008	-0.070	0.068	-0.013	0.006	0.078	-0.026	0.103	0.135	0.038
O	0.106	-0.090	0.095	-0.001	-0.051	0.154	1.000	0.022	0.087	0.046	0.035	0.182	0.158	0.102	-0.002	0.047	0.048
P	0.039	-0.067	0.017	0.038	-0.019	0.008	0.022	1.000	0.039	0.040	0.057	-0.092	-0.002	0.057	0.020	-0.018	0.001
Q	0.027	0.190	-0.039	-0.019	0.098	-0.070	0.087	0.039	1.000	-0.052	0.033	0.040	0.067	0.026	-0.155	0.059	-0.047
R	-0.052	-0.046	0.089	0.054	0.090	0.068	0.046	0.040	-0.052	1.000	0.086	0.074	0.118	0.105	-0.121	-0.014	0.023
S	-0.030	0.029	0.009	0.180	0.009	-0.013	0.035	0.057	0.033	0.086	1.000	0.158	0.153	0.087	-0.105	-0.040	-0.005
T	-0.019	0.050	0.028	-0.014	-0.003	0.006	0.182	-0.092	0.040	0.074	0.158	1.000	0.013	0.054	-0.002	-0.024	0.038
U	-0.039	-0.102	-0.004	0.186	0.154	0.078	0.158	-0.002	0.067	0.118	0.153	0.013	1.000	0.235	-0.042	0.241	0.018
V	0.059	0.067	0.014	0.038	0.086	-0.026	0.102	0.057	0.026	0.105	0.087	0.054	0.235	1.000	0.094	-0.020	0.069
W	-0.027	0.010	0.021	-0.136	-0.066	0.103	-0.002	0.020	-0.155	-0.121	-0.105	-0.002	-0.042	0.094	1.000	-0.039	0.172
X	0.059	-0.076	0.115	0.126	0.150	0.135	0.047	-0.018	0.059	-0.014	-0.040	-0.024	0.241	-0.020	-0.039	1.000	-0.043
Y	0.015	0.073	-0.068	-0.023	-0.095	0.038	0.048	0.001	-0.047	0.023	-0.005	0.038	0.018	0.069	0.172	-0.043	1.000

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APPENDIX C. S-PLUS SIMULATION CODE

```
hfacs.simulation.program <-
function(mtrix, catvector, lambda, time, iterations, mishaps){

  #mtrix is asymmetric binary matrix (HFACSC_H, HFACSC_T, HFACSC_C)
  #catvector is a 1x17 vector used to choose causal factors for the simulation
  #lambda is the accident arrival rate
  #time is the flight hours/100,000
  #iterartions = 1000
  #mishaps is the number of mishaps (or rows) in the mtrix matrix

  counter <- rep(0, iterations)
  poisson <- rep(0, iterations)
  counter.data <- 0

  for(i in 1:iterations) {

    #generate number of accidents E(count accidents)= lambda*time
    randompoisson <- rpois(1, lambda * time)
    poisson[i] <- randompoisson
    #generate random uniform selection of actual HFACS accident
    randomuniform <- round(runif(randompoisson, 1, mishaps))
    #generate matrix of randomly selected accidents
    acc.data <- mtrix[randomuniform, ]
    acc.matrix <- as.matrix(acc.data)
    solution.data <- catvector %*% t(acc.matrix)
    count.data <- sum(solution.data == sum(catvector))
    counter[i] <- count.data
  }

  #printout mean and 95% Confidence Intervals
  print(mean(counter))
  print(quantile(poisson, 0.025))
  print(quantile(poisson, 0.975))
  print(quantile(counter, 0.025))
  print(quantile(counter, 0.975))

}
```

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APPENDIX D. MEAN AND 95 PERCENT CI FOR SIMULATION RUNS

Table D1. Mean and 95% CIs of Causal Factors for Simulation Runs.

	Rotary Wing		TACAIR		Combined Rotary Wing and TACAIR	
Sets	Mean	95% CI	Mean	95% CI	Mean	95% CI
Singles						
I	4.048	(1, 8)	7.99	(3, 14)	12.26	(6, 20)
J	4.862	(1, 10)	7.098	(2, 13)	12.08	(6, 19)
K	2.263	(0, 5)	3.067	(0, 7)	5.62	(2, 11)
L	2.193	(0, 6)	2.673	(0, 6)	4.834	(1, 9)
N	1.634	(0, 5)	2.603	(0, 6)	4.218	(1, 9)
O	5.69	(2, 11)	8.551	(3, 15)	14.64	(8, 23)
Q	6.172	(2, 12)	6.248	(2, 11)	12.24	(6, 20)
S	2.521	(0; 6)	3.038	(0, 7)	5.811	(1, 11)
W	1.794	(0, 5)	3.72	(1, 8)	5.46	(1, 11)
Y	2.113	(0, 5)	3.769	(1, 8)	5.981	(2, 11)
Combinations						
Q & O	4.479	(1, 9)	4.279	(1, 9)	8.675	(4, 15)
Q & J	3.665	(0, 8)	4.255	(1, 9)	7.949	(3, 13)
Q & I	3.219	(0, 7)	3.946	(1, 8)	7.201	(3, 13)
O & J	2.905	(0, 6)	4.675	(1, 9)	7.672	(3, 14)
O & I	2.817	(0, 6)	5.925	(2, 11)	8.94	(4, 15)
I & J	2.213	(0, 6)	3.515	(0, 7)	5.995	(2, 11)
Q & S	2.055	(0, 5)	1.366	(0, 4)	3.425	(0, 7)
Q & K	1.861	(0, 5)	1.222	(0, 4)	2.987	(0, 7)
O & L	1.722	(0, 5)	1.579	(0, 4)	3.288	(0, 7)
O & S	1.646	(0, 5)	2.278	(0, 6)	4.077	(1, 8)
O & K	1.689	(0, 5)	2.484	(0, 6)	4.185	(1, 8)
Q & L	1.641	(0, 5)	1.111	(0, 4)	2.685	(0, 6)
Q & M	1.555	(0, 4)	0.931	(0, 3)	2.523	(0, 6)
O & Y	1.585	(0, 4)	2.667	(0, 6)	4.286	(1, 9)
Q & Y	1.468	(0, 4)	1.743	(0, 5)	3.238	(0, 7)
O & W	1.113	(0, 3)	2.514	(0, 6)	3.652	(0, 8)
N & K	1.528	(0, 4)	2.053	(0, 5)	3.513	(0, 7)
O & T	0.979	(0, 3)	1.135	(0, 3)	2.168	(0, 5)
O & U	0.704	(0, 3)	0.739	(0, 3)	1.457	(0, 4)
O & N	1.44	(0, 4)	2.015	(0, 5)	3.557	(0, 7)
O & V	0.687	(0, 2)	0.835	(0, 3)	1.518	(0, 4)
Q & T	0.978	(0, 3)	0.572	(0,2)	1.523	(0, 4)
Q & U	0.722	(0, 3)	0.353	(0, 2)	1.116	(0, 4)
O & M	1.351	(0, 4)	0.906	(0, 3)	2.261	(0, 6)
V & I	0.341	(0, 2)	0.828	(0, 3)	1.18	(0, 4)
Q & N	1.294	(0, 4)	0.873	(0, 3)	2.127	(0, 5)

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APPENDIX E. CAUSAL FACTOR RATE/100,000 FLIGHT HOURS

Table E1. Rotary Wing FY 90—FY 98 Causal Factor Rate/100,000 Flight Hours.

FY	A	E	I	J	K	F	L	M	B	G	N	O	P	H	Q	R	C	S	T	U	V	D	W	X	Y
90	1.76	1.54	0.66	1.10	0.00	1.10	0.66	0.44	1.54	1.32	0.22	1.32	0.00	1.54	1.54	0.00	1.10	0.88	0.22	0.66	0.00	0.22	0.22	0.00	0.00
91	4.00	3.58	1.89	1.89	1.68	1.47	0.84	0.84	3.79	3.15	1.47	2.73	0.00	2.94	2.94	0.00	1.68	0.84	0.63	0.21	0.63	2.10	1.26	0.00	1.47
92	0.95	0.71	0.24	0.24	0.24	0.24	0.24	0.24	0.95	0.95	0.24	0.95	0.00	0.71	0.71	0.24	0.71	0.00	0.48	0.48	0.24	0.71	0.24	0.00	0.48
93	3.20	2.71	1.48	2.21	1.23	1.23	0.49	0.98	2.95	2.46	0.49	2.21	0.25	2.46	2.46	0.00	0.98	0.49	0.25	0.25	0.25	1.72	1.23	0.00	1.23
94	2.92	2.92	2.12	1.59	0.53	1.33	1.06	0.27	2.12	1.86	0.00	1.86	0.53	1.59	1.59	0.00	1.06	0.80	0.00	0.00	0.27	0.80	0.00	0.00	0.80
95	2.34	2.34	1.04	2.08	0.26	0.78	0.52	0.26	2.34	1.82	0.26	1.56	0.26	1.56	1.56	0.00	1.04	0.78	0.26	0.00	0.00	0.52	0.52	0.00	0.00
96	0.83	0.83	0.55	0.55	0.28	0.55	0.55	0.28	0.83	0.83	0.00	0.55	0.28	0.83	0.83	0.00	0.83	0.83	0.28	0.00	0.28	0.28	0.28	0.00	0.28
97	2.49	2.18	1.56	1.56	0.93	0.93	0.62	0.31	2.49	1.87	0.93	1.87	0.31	2.49	2.49	0.31	1.56	1.56	0.31	0.31	0.00	0.62	0.00	0.00	0.62
98	2.31	2.31	1.74	1.16	0.87	0.58	0.00	0.00	2.03	2.03	0.58	1.74	0.29	1.74	1.74	0.00	0.58	0.58	0.00	0.29	0.00	0.58	0.00	0.00	0.58

Table E2. TACAIR FY 90—FY 98 Causal Factor Rate/100,000 Flight Hours.

FY	A	E	I	J	K	F	L	M	B	G	N	O	P	H	Q	R	C	S	T	U	V	D	W	X	Y
90	3.95	3.63	2.84	2.37	0.47	1.42	1.11	0.47	3.00	2.21	0.47	2.21	0.16	1.58	1.58	0.00	1.42	1.26	0.32	0.00	0.16	1.90	0.63	0.00	1.42
91	3.48	3.33	1.67	2.12	1.06	1.67	1.21	0.61	2.73	2.12	0.45	1.97	0.00	1.51	1.51	0.00	1.21	0.76	0.76	0.00	0.15	1.67	1.21	0.00	0.76
92	2.51	2.51	1.51	1.67	1.17	0.67	0.17	0.50	2.34	2.18	1.00	1.84	0.33	1.17	1.00	0.33	1.17	0.67	0.17	0.33	0.33	1.17	0.50	0.00	0.84
93	3.99	3.81	2.08	2.43	1.04	1.56	1.21	0.35	3.99	3.29	0.87	2.95	0.35	2.60	2.43	0.35	1.56	1.04	0.17	0.52	0.69	2.60	1.91	0.00	1.56
94	1.72	1.72	0.96	1.15	0.19	0.19	0.00	0.19	1.34	1.15	0.19	1.15	0.38	1.15	1.15	0.00	0.19	0.00	0.19	0.00	0.00	0.38	0.19	0.00	0.38
95	3.18	3.18	1.99	1.59	1.19	1.19	0.60	0.79	2.58	2.38	0.40	2.38	0.00	1.59	1.59	0.00	0.79	0.60	0.20	0.20	0.20	1.19	0.40	0.00	0.99
96	3.54	3.34	2.50	1.04	0.42	0.83	0.63	0.63	3.13	3.13	1.25	2.92	0.00	1.46	1.25	0.21	1.46	0.83	0.42	0.21	0.21	1.67	1.25	0.21	1.25
97	2.85	2.85	2.14	0.95	0.71	0.47	0.00	0.47	2.85	1.90	0.71	1.66	0.24	2.14	1.66	0.47	0.71	0.71	0.24	0.24	0.24	1.19	0.95	0.00	0.24
98	1.72	1.72	0.74	1.23	0.25	0.00	0.00	0.00	1.48	0.98	0.00	0.98	0.00	1.23	1.23	0.00	0.25	0.25	0.00	0.00	0.00	0.98	0.49	0.00	0.49

Table E3. Combined Rotary Wing and TACAIR FY 90—FY 98 Causal Factor Rate/100,000 Flight Hours.

FY	A	E	I	J	K	F	L	M	B	G	N	O	P	H	Q	R	C	S	T	U	V	D	W	X	Y
90	3.03	2.76	1.93	1.84	0.28	1.29	0.92	0.46	2.39	1.84	0.37	1.84	0.09	1.56	1.56	0.00	1.29	1.10	0.28	0.28	0.09	1.19	0.46	0.00	0.83
91	3.70	3.43	1.76	2.02	1.32	1.58	1.06	0.70	3.17	2.55	0.88	2.29	0.00	2.11	2.11	0.00	1.41	0.79	0.70	0.09	0.35	1.85	1.23	0.00	1.06
92	1.87	1.77	0.98	1.08	0.79	0.49	0.20	0.39	1.77	1.67	0.69	1.47	0.20	0.98	0.88	0.29	0.98	0.39	0.29	0.39	0.29	0.98	0.39	0.00	0.69
93	3.66	3.36	1.83	2.34	1.12	1.42	0.92	0.61	3.56	2.95	0.71	2.64	0.31	2.54	2.44	0.20	1.32	0.81	0.20	0.41	0.51	2.24	1.63	0.00	1.42
94	2.22	2.22	1.44	1.33	0.33	0.67	0.44	0.22	1.67	1.44	0.11	1.44	0.44	1.33	1.33	0.00	0.56	0.33	0.11	0.00	0.11	0.56	0.11	0.00	0.56
95	2.81	2.81	1.58	1.80	0.79	1.01	0.56	0.56	2.48	2.14	0.34	2.03	0.11	1.58	1.58	0.00	0.90	0.68	0.23	0.11	0.11	0.90	0.45	0.00	0.56
96	2.37	2.25	1.66	0.83	0.36	0.71	0.59	0.47	2.13	2.13	0.71	1.90	0.12	1.19	1.07	0.12	1.19	0.83	0.36	0.12	0.24	1.07	0.83	0.12	0.83
97	2.70	2.56	1.89	1.21	0.81	0.67	0.27	0.40	2.70	1.89	0.81	1.75	0.27	2.29	2.02	0.40	1.08	1.08	0.27	0.27	0.13	0.94	0.54	0.00	0.40
98	1.99	1.99	1.20	1.20	0.53	0.27	0.00	0.00	1.73	1.46	0.27	1.33	0.13	1.46	1.46	0.00	0.40	0.40	0.00	0.13	0.00	0.80	0.27	0.00	0.53

Table E4. Rotary Wing FY 90—FY 97 Average Causal Factor Rate/100,000 Flight Hours.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	1.19	0.66	0.22	0.34	0.16	0.16	0.81	0.09	0.90	0.00	0.37	0.16	0.06	0.09	0.22	0.00	0.34
J		1.40	0.44	0.34	0.16	0.28	0.84	0.16	1.06	0.03	0.44	0.16	0.00	0.12	0.31	0.00	0.37
K			0.66	0.19	0.16	0.44	0.47	0.06	0.53	0.00	0.19	0.12	0.03	0.09	0.19	0.00	0.16
L				0.62	0.12	0.19	0.50	0.09	0.47	0.03	0.41	0.12	0.12	0.06	0.06	0.00	0.19
M					0.47	0.09	0.41	0.00	0.47	0.03	0.22	0.06	0.16	0.12	0.09	0.00	0.16
N						0.47	0.41	0.03	0.37	0.00	0.12	0.09	0.06	0.03	0.19	0.00	0.16
O							1.65	0.09	1.31	0.03	0.50	0.28	0.22	0.19	0.31	0.00	0.47
P								0.19	0.12	0.00	0.12	0.00	0.00	0.03	0.03	0.00	0.06
Q									1.78	0.06	0.59	0.28	0.22	0.19	0.31	0.00	0.44
R										0.06	0.00	0.03	0.03	0.03	0.00	0.00	0.03
S											0.75	0.12	0.16	0.06	0.06	0.00	0.16
T												0.31	0.06	0.06	0.06	0.00	0.09
U													0.25	0.03	0.00	0.00	0.09
V														0.22	0.06	0.00	0.12
W															0.50	0.00	0.22
X																0.00	0.00
Y																	0.62

Table E5. TACAIR FY 90—FY 97 Average Causal Factor Rate/100,000 Flight Hours.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	1.96	0.86	0.34	0.32	0.14	0.39	1.43	0.14	0.98	0.09	0.43	0.18	0.14	0.20	0.52	0.02	0.57
J		1.73	0.30	0.36	0.30	0.27	1.14	0.02	1.02	0.07	0.43	0.23	0.14	0.18	0.48	0.00	0.59
K			0.80	0.27	0.18	0.50	0.61	0.05	0.30	0.09	0.20	0.07	0.07	0.05	0.20	0.02	0.18
L				0.66	0.11	0.20	0.39	0.02	0.27	0.05	0.16	0.02	0.09	0.07	0.11	0.02	0.16
M					0.50	0.11	0.23	0.05	0.23	0.05	0.07	0.05	0.02	0.02	0.09	0.02	0.05
N						0.66	0.52	0.05	0.23	0.07	0.16	0.05	0.07	0.05	0.20	0.02	0.20
O							2.14	0.16	1.05	0.14	0.55	0.30	0.18	0.20	0.61	0.02	0.66
P								0.18	0.11	0.02	0.02	0.00	0.02	0.02	0.07	0.00	0.05
Q									1.52	0.05	0.34	0.14	0.09	0.11	0.32	0.02	0.43
R										0.16	0.09	0.02	0.02	0.02	0.00	0.00	0.05
S											0.75	0.16	0.07	0.11	0.18	0.00	0.25
T												0.32	0.00	0.02	0.09	0.00	0.11
U													0.18	0.09	0.07	0.02	0.05
V														0.25	0.11	0.00	0.07
W															0.89	0.00	0.36
X																0.02	0.00
Y																	0.96

Table E6. Combined Rotary Wing and TACAIR FY 90—FY 97 Average Causal Factor Rate/100,000 Flight Hours.

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
I	1.63	0.78	0.29	0.33	0.14	0.29	1.17	0.12	0.95	0.05	0.41	0.17	0.11	0.16	0.39	0.01	0.47
J		1.59	0.36	0.36	0.24	0.28	1.01	0.08	1.04	0.05	0.43	0.20	0.08	0.16	0.41	0.00	0.50
K			0.74	0.24	0.17	0.47	0.55	0.05	0.39	0.05	0.20	0.09	0.05	0.07	0.20	0.01	0.17
L				0.64	0.12	0.20	0.43	0.05	0.36	0.04	0.26	0.07	0.11	0.07	0.09	0.01	0.17
M					0.49	0.11	0.30	0.03	0.33	0.04	0.13	0.05	0.08	0.07	0.09	0.01	0.09
N						0.58	0.47	0.04	0.29	0.04	0.14	0.07	0.07	0.04	0.20	0.01	0.18
O							1.93	0.13	1.16	0.09	0.53	0.29	0.20	0.20	0.49	0.01	0.58
P								0.18	0.12	0.01	0.07	0.00	0.01	0.03	0.05	0.00	0.05
Q									1.63	0.05	0.45	0.20	0.14	0.14	0.32	0.01	0.43
R										0.12	0.05	0.03	0.03	0.03	0.00	0.00	0.04
S											0.75	0.14	0.11	0.09	0.13	0.00	0.21
T												0.32	0.03	0.04	0.08	0.00	0.11
U													0.21	0.07	0.04	0.01	0.07
V														0.24	0.09	0.00	0.09
W															0.72	0.00	0.30
X																0.01	0.00
Y																	0.82

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APPENDIX F. EXCERPT FROM DRAFT OPNAV 3750.6R (APPENDIX O) HFACS TAXONOMY

Human Factors Analysis and Classification System (HFACS)

Drawing upon Reason's (1990) concept of latent and active failures, a framework was developed to identify the "holes" called the Human Factors Analysis and Classification System (HFACS). HFACS describes four levels of failure: 1) Unsafe Acts, 2) Preconditions for Unsafe Acts, 3) Unsafe Supervision, and 4) Organizational Influences. A brief description of the major components and causal categories follows, beginning with the level most closely tied to the accident, unsafe acts.

1. Unsafe Acts

The unsafe acts committed by aircrew generally take on two forms, errors and violations. The first, errors, are not surprising given the fact that human beings by their very nature make errors. Consequently, aircrew errors are seen in most mishaps – often as that last fatal flaw before a mishap occurs. Violations, on the other hand, represent the willful disregard for the rules and typically occur less frequently. Still, not all errors are alike. Likewise, there are different types of violations. As such, the unsafe acts aircrew commit can be classified among three basic error types (skill-based, decision, and perceptual) and two forms of violations (infractions and exceptional). Each will be described in turn (Figure 2).

Using this simple classification scheme, the investigator must first decide if an unsafe act (active failure) was committed by the operator (aircrew, maintainer, etc.). If so, the investigator must then decide if an error occurred or a rule was willfully violated. Once this is done, the investigator can further define the causal factor as a specific type of error or violation as described below.

Error

Skill-based Errors. Skill-based behavior is best described as those "stick-and-rudder" and other basic flight skills that occur without significant conscious thought. As a result, skill-based actions are particularly vulnerable to failures of attention and/or memory. In fact, attention failures have been linked to many skill-based errors such as the breakdown in visual scan patterns, task fixation, the inadvertent activation of controls, and the misordering of steps in a procedure, among others (Table 1). Consider, for

example, the pilot so intent on putting bombs on target that he disregards his low altitude warning only to collide with the ground. Closer to home, have you ever locked yourself out of your car or missed your exit because your were either distracted, in a hurry, or daydreaming? These are all examples of attention failures that occur during highly automatized behavior. While on the ground they may be frustrating, in the air they can become catastrophic.

In contrast to attention failures, memory failures often appear as omitted items in a checklist, place losing, or forgotten intentions. For example, most of us have experienced going to the refrigerator only to forget what we came for. Likewise, it's not difficult to imagine that in emergency situations, when under stress, steps in boldface emergency procedures or radio calls can be missed. Even when not particularly stressed however, individuals have forgotten to set the flaps on approach or lower the landing gear.

Skill-based errors can happen even when no apparent attention of memory failure is present. The individual flying skill/techniques of Naval aviators differ from one pilot to next. We've all known individuals that fly smooth and effortless and those who make every mission an adventure. It is the skill-based errors of the latter that often leads to mishaps as well. The bottom line is that skill-based errors are unintended behaviors. That is, individuals typically do not choose to limit their scan patterns, forget a boldface procedure, or fly poorly – it just happens, unbeknownst to the individual.

Decision Errors. The second error form, decision errors, represent intentional behavior that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation. Often referred to as "honest mistakes", these unsafe acts represent the actions or inactions of individuals whose heart is in the right place, but they either did not have the appropriate knowledge available or just simply chose poorly. Regardless of the outcome, the individual made a conscious decision.

Decision errors come in many forms, and occur for a variety of reasons. However, they typically represent poor decisions, improper procedural execution, or the misinterpretation or misuse of relevant information (Table 1). The bottom line is that for good or bad the individual made a conscious choice and elected to do what was done in the cockpit – unfortunately, in the case of mishaps, it didn't work.

Table 1. Select examples of Unsafe Acts of Operators	
Unsafe Acts of Operators	
Errors	Violations
<u>Skill-based Errors</u> Breakdown in Visual Scan Delayed Response Omitted Step in Procedure	<u>Routine (Infractions)</u> Failed to Adhere to Brief Violation of NATOPS/Regulations/SOP
<u>Decision Errors</u> Improper Approach/Landing Improper Procedure Misdiagnosed Emergency	<u>Exceptional</u> Not Current/Qualified for Mission Violation of NATOPS/Regulations/SOP
<u>Perceptual Errors</u> Misjudged Distance/Altitude/Airspeed Spatial Disorientation Visual Illusion	

<u>Perceptual Errors</u>. Not surprisingly, when your perception of the world is different then reality, errors can, and often do, occur. Typically, perceptual errors occur when sensory input is degraded or 'unusual', as is the case when visual illusions or spatial disorientation occurs (Table 1). Visual illusions occur when the brain tries to 'fill in the gaps' with what it feels belongs in a visually impoverished environment, like that seen at night or in the weather. Likewise, spatial disorientation occurs when the vestibular system cannot resolve your orientation in space and therefore makes a "best guess" -- typically when visual (horizon) cues are absent at night or in weather. In either event, the individual is left to make a decision based on faulty information leading to and error, and often a mishap. Likewise, it is often quite difficult to judge precise distance and closure between aircraft and the ground when relative cues like clouds or terrain features are absent. Consequently, aircrews are left to make control inputs based upon misperceived or absent information. Tragically, these sorts of errors often lead to midair collisions or controlled flight into terrain.

Violations

Routine/Infractions. Violations in general are the willful departure from authority that simply cannot be tolerated. We have identified two distinct types of violations (Table 1). The first, infractions, tend to be routine/habitual by nature constituting a part of the individual's behavioral repertoire. For example, the individual that drives consistently 5-10 mph faster than allowed by law. While certainly against the law, many folks do it. Furthermore, if you go 64 in a 55 mph zone, you always drive 64 in a 55 mph zone. That is, you 'routinely' violate the law. Commonly referred to as "bending" the rules, these violations are often tolerated and, in effect, sanctioned by supervisory authority (that is, you're not likely to get a ticket going 64 in a 55). If however, the local authorities started handing out tickets for exceeding the speed limit on the highway by 9 mph (like is often done on military installations) then it is less likely that individuals would violate the rules. Therefore, by definition, if a routine violation/infraction is identified, one must look further up the supervisory chain to identify those that are condoning those violations.

Exceptional. Unlike routine violations, exceptional violations appear as isolated departures from authority, not necessarily indicative of an individual's typical behavior pattern nor condoned by management. For example, an isolated instance of driving 105 mph in a 55 mph zone, or in naval aviation, *flathatting*, is considered an exceptional violation. It is important to note that while most exceptional violations are heinous, they are not considered 'exceptional' because of their extreme nature. Rather, they are considered exceptional because they are neither typical of the individual nor condoned by authority.

2. Preconditions for Unsafe Acts

Arguably the unsafe acts of operators can be directly linked to nearly 80 percent of all Naval aviation mishaps. However, simply focusing on unsafe acts is like focusing on a fever without understanding the underlying disease causing it. As such, investigators must dig deeper into why the unsafe acts took place. As a first step, we describe two major subdivisions of unsafe aircrew conditions, each with their specific causal categories. Specifically, they include the Substandard Conditions of operators (i.e., Adverse Mental States, Adverse Physiological States, and Physical/Mental

Limitations) as well as those Substandard Practices they commit (Figure 3). Each are described briefly below.

Substandard Conditions of Operators

Adverse Mental States. Being prepared mentally is critical in nearly every endeavor, perhaps more so in aviation. As such, the category of adverse mental states, was created to account for those mental conditions that affect performance (Table 2). Principle among these is the loss of situational awareness, task fixation, distraction, and *mental* fatigue due to sleep loss or other stressors. Also included in this category are personality traits and pernicious attitudes such as overconfidence, complacency, and misplaced motivation. For example, if an individual is mentally tired for whatever reason, the likelihood that an error would occur increases. Likewise, overconfidence, arrogance, and other pernicious attitudes will influence the likelihood that a violation is committed. While errors and violations are important causal factors, adverse mental states such as these are no less important, perhaps even more so, in the causal sequence.

Adverse Physiological States. The second category, adverse physiological states, refers to those medical or physiological conditions that preclude safe operations (Table 2). Particularly important to Naval aviation are conditions such as spatial disorientation, visual illusions, G-induced loss of consciousness (G-LOC), hypoxia, *physical* fatigue, and the myriad of pharmacological and medical abnormalities known to affect performance. If, for example, an individual were suffering from an inner ear infection, the likelihood of spatial disorientation occurring when entering IMC goes up markedly. Consequently, the medical condition must be addressed within the causal chain of events.

Physical/Mental Limitations. The third, and final, category of Aeromedical Conditions, Physical/Mental Limitations, refers to those instances when the mission requirements exceed the capabilities of the individual at the controls. Physical/Mental Limitations can take many forms (Table 2). For example, at night our visual systems are limited by the capability of the photosensors in our eyes and hence vision is severely degraded. Yet, like driving a car, we do not necessarily slow down or take additional precautions. In aviation, this often results in not seeing other aircraft, obstacles, or power lines due to the size or contrast of the object in the visual field. Similarly, there are occasions when the time required to complete a task or maneuver exceeds human

capacity. It is well documented that if individuals are required to respond quickly (i.e., less time is available to consider all the possibilities or choices thoroughly), the probability of making an error goes up markedly.

There are two additional instances of physical/mental limitations that need to be addressed; albeit they are often overlooked in most mishap investigations. They involve individuals who simply are not compatible with aviation. For example, some individuals simply don't have the physical strength to operate in high-G environments or for anthropometric reasons simply have difficulty reaching the controls. In other words, cockpits have traditionally not been designed with all shapes, sizes, and physical abilities in mind. Likewise, not everyone has the mental ability or aptitude for flying Naval aircraft. Just as not all of us can be concert pianists or NFL linebackers, we can't all fly Naval aircraft. The hard part is identifying whether this might of played a role in the mishap causal sequence.

Table 2. Select examples of Unsafe Aircrew Conditions

Preconditions for Unsafe Acts	
Aeromedical	Crew Resource Management
Adverse Mental States	Failed to Back-up
Channelized Attention	Failed to Communicate/Coordinate
Complacency	Failed to Conduct Adequate Brief
Loss of Situational Awareness	
	Personal Readiness
Adverse Physiological States	Excessive Physical Training
G-Induced Loss of Consciousness	Self-Medicating
Impaired Physiological State	Violation of Crew Rest Requirement
Physical Fatigue	Violation of Bottle-to-Brief Requirement
Physical/Mental Limitation	
Insufficient Reaction Time	
Visual Limitation	
Incompatible Intelligence/Aptitude	

Substandard Practices of Operators

Crew Resource Mismanagement. To account for occurrences of poor coordination among aircrew and other personnel associated with the safe conduct of the flight, the category of crew resource management was created (Table 2). This includes coordination both within and between aircraft, ATC, and maintenance control, as well as

facility and other support personnel. Anywhere communication between individuals is required, the potential for miscommunication, or simply poor resource management, exists. However, aircrew coordination does not stop with the aircrew in flight. It also includes coordination before and after the flight with the brief and debrief of the aircrew. Literally volumes have been written on the topic, yet it still continues to permeate both fixed-wing and rotary-wing aviation, as well as multi-crew and single-seat aircraft. The conscientious investigator must always be aware of the potential for poor CRM practices.

Personal Readiness. In aviation, or for that matter in any occupational setting, individuals are expected to show up for work ready to perform at optimal levels. For Naval aviation however, personal readiness failures occur when individuals fail to prepare physically or mentally for flight. For instance, violations of crew rest requirements, bottle-to-brief rules, and self-medicating all will affect performance in the aircraft. It's not hard to imagine that when you violate crew rest requirements, you run the risk of mental fatigue and other adverse mental states. (*Note that violations that effect personal readiness are not considered "unsafe act, violation" since they typically do not happen in the cockpit, nor are they active failures with direct and immediate consequences*)

Still, not all personal readiness failures occur as a result of violations of rules. For example, running 10 miles before piloting an aircraft may not be against any existing regulations, yet it may impair the physical and mental capabilities of the individual enough to degrade performance and elicit unsafe acts. Likewise, the traditional "candy bar and coke" lunch of the naval aviator may sound good but may not be sufficient to sustain performance in the rigorous environment of military aviation. Even cramming for exams may significantly impair your sleep and may in some cases influence your performance the next day in the cockpit. While, there may be no rules governing such behavior, aircrew must be their own best judge. Certainly, additional education and physical exercise is a good thing when taken in moderation, but aircrew must always assess their condition objectively before manning the aircraft.

3. Unsafe Supervision

It is the experience of the Naval Safety Center that often the mishap causal chain of events can be traced back up the supervisory chain of command. As such, we have

identified four categories of Unsafe Supervision: Inadequate Supervision, Planned Inappropriate Operations, Failed to Correct a Known Problem, and Supervisory Violations (Figure 4). Each are described briefly below.

Inadequate Supervision. The role of any supervisor is to provide the opportunity to succeed. To do this the supervisor, no matter what level he operates at, must provide guidance, training opportunities, leadership, motivation, and the proper role model. Unfortunately, this is not always the case. It's not difficult to conceive of a situation where adequate crew resource management training was either not provided, or the opportunity to attend was not afforded, to a particular aircrew member. Conceivably, his aircrew coordination skills would be compromised and if put into an adverse situation (an emergency for instance), he would be at risk for errors and potentially a mishap. Therefore, the category Inadequate Supervision was created to account for those times when supervision proves inappropriate, improper, or may not occur at all (Table 3).

Planned Inappropriate Operations. Occasionally, the operational tempo and/or schedule is planned such that individuals are put at unacceptable risk, crew rest is jeopardized, and ultimately performance is adversely affected. Such operations, though arguably unavoidable during emergency situations, are unacceptable during normal operations. Therefore, we have created a second category, Planned Inappropriate Operations, to account for these supervisory failures (Table 3). Included in this category are issues of crew pairing and improper manning. It's not surprising to anyone that when two individuals with marginal skills are paired together, problems can, and often do, arise. With down-sizing and the current level of operational commitments, it is difficult to manage crews. However, pairing two weak or inexperienced aircrew together on the most difficult mission may not be prudent.

Failure to Correct a Known Problem. The third category of known unsafe supervision, Failed to Correct a Problem, refers to those instances when deficiencies among individuals, equipment, training or other related safety areas are "known" to the supervisor, yet are allowed to continue uncorrected (Table 3). For example, the failure to consistently correct or discipline inappropriate behavior certainly fosters an unsafe atmosphere, but is not considered a violation if no specific rules or regulations were broken.

Supervisory Violations. Supervisory violations, on the other hand, are reserved for those instances when existing rules and regulations are willfully disregarded by supervisors when managing assets (Table 3). For instance, permitting an individual to operate an aircraft without current qualifications or license is a flagrant violation that invariably sets the stage for the tragic sequence of events that predictably follow.

Table 3. Select examples of Unsafe Supervision

Inadequate Supervision	Failed to Correct a Known Problem
Failed to Provide Guidance	Failed to Correct Document in Error
Failed to Provide Operational Doctrine	Failed to Identify an At-Risk Aviator
Failed to Provide Training	Failed to Initiate Corrective Action
Planned Inappropriate Operations	Supervisory Violations
Failed to Provide Adequate Brief Time	Failed to Enforce NATOPS/Regs/SOP
Improper Manning	Failed to Enforce T&R Manual
Mission Not IAW with NATOPS/Regs/SOP	Authorized Unqualified Crew for Flight

4. Organizational Influences

Fallible decisions of upper-level management directly effect supervisory practices, as well as the conditions and actions of operators. These latent failures generally revolve around issues related to resource management, organizational climate, and operational processes.

Resource Management. This category refers to the management, allocation, and maintenance of organizational resources, such as human, monetary, and equipment/facilities. The term 'human' refers to the management of operators, staff, and maintenance personnel. Issues that directly influence safety include selection (including background checks), training, and staffing/manning. Monetary issues refer to the management of nonhuman resources, primarily monetary resources. For example, excessive cost-cutting, a lack of funding for proper and safe equipment and resources both have adverse effects on operator performance and safety. Finally, Equipment/Facility refers to issues related to equipment design, including the purchasing of unsuitable equipment, inadequate design of work spaces, and failures to correct known design flaws. Management should ensure that human factors engineering principles are known and utilized and that specifications for equipment and work space design are identified and met.

Table 4. Select examples of Organizational Influences	
<u>Resource/Acquisition Management</u>	<u>Organizational Process</u>
Human Resources	Operations
Staffing/Manning	Operational tempo
Training	Time pressure
Monetary/Budget Resources	Procedures
Excessive cost cutting	Standards
Lack of funding	Instructions
Equipment/Facility Resources	Oversight
Poor design	Risk Management
Unsuitable equipment	Safety Programs
<u>Organizational Climate</u>	
Structure	
Chain-of-command	
Communication	
Policies	
Hiring and firing	
Drugs and alcohol	
Culture	
Norms and rules	
Values and beliefs	

<u>Organizational Climate</u>. Organizational climate refers to a broad class of organizational variables that influence worker performance (Glick, 1985). It can be defined as the "situationally based consistencies in the organization's treatment of individuals." (Jones, 1988). In general, organizational climate is the prevailing atmosphere or environment within the organization. Within the present classification system, climate is broken down into three categories- structure, policies, and culture. The term 'structure' refers to the formal component of the organization (Mintzberg, 1993). The "form and shape" of an organization are reflected in the chain-of-command, delegation of authority and responsibility, communication channels, and formal accountability for actions. Organizations with maladaptive structures (i.e., do not optimally match to their operational environment or are unwilling to change), will be more prone to accidents and "will ultimately cease to exists." (Muchinsky, 1997). Policies refer to a course or method of action that guides present and future decisions. Policies may refer to hiring and firing, promotion, retention, raises, sick leave, drugs and

alcohol, overtime, accident investigations, use of safety equipment, etc. When these policies are ill-defined, adversarial, or conflicting, safety may be reduced. Finally, culture refers to unspoken or unofficial rules, values, attitudes, beliefs, and customs of an organization. "The way things really get done around here." Other issues related to culture included organizational justice, psychological contracts, organizational citizenship behavior, esprit de corps, and union/management relations. All these issues affect attitudes about safety and the value of a safe working environment.

Organizational Process. This category refers to the formal process by which things get done in the organization. It is subdivided into three broad categories - operations, procedures, and oversight. The term 'operations' refers to the characteristics or conditions of work that have been established by management. These characteristics included operational tempo, time pressures, production quotas, incentive systems, schedules, etc. When set up inappropriately, these working conditions can be detrimental to safety. Procedures are the official or formal procedures as to how the job is to be done. Examples include performance standards, objectives, documentation, instructions about procedures, etc. All of these, if inadequate, can negatively impact employee supervision, performance, and safety. Finally, oversight refers to management's monitoring and checking of resources, climate, and processes to ensure a safe and productive work environment. Issues here relate to organizational self-study, risk management, and the establishment and use of safety programs.

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